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CHARLES D. WALCOTT, DIRECTOR

A STUDY

OF THE

FAUNA OF THE HAMILTON FORMATION OF THE CAYUGA LAKE SECTION IN CENTRAL NEW YORK.

BY

HERDMAN FITZGERALD CLELAND

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LETTER OF TRANSMITTAL.

YALE UNIVERSITY,
New Haven, Conn., June 23, 1902.

SIR: I have the honor to transmit herewith, for publication as a bulletin of the United States Geological Survey, the manuscript of a paper entitled A Study of the Fauna of the Hamilton Formation of the Cayuga Lake Section in Central New York, prepared at my suggestion by Herdman Fitzgerald Cleland.

Respectfully, yours,
HENRY SHALER WILLIAMS,
Geologist and Paleontologist.

Hon. CHARLES D. WALCOTT,
Director of United States Geological Survey.

INTRODUCTION.

By Henry Shaler Williams.

The following paper is a contribution to the knowledge of the fossil faunas of the Devonian of the United States. It was begun by Mr. Cleland as a piece of research work in the course of study for the doctorate degree at Yale University, and was used as a thesis in taking the degree of doctor of philosophy in June, 1900. During the summer of 1901 some additional work was put on it, based upon more extended field work.

The value of the investigation consists chiefly in the statistics it furnishes as to the approximate composition of each of the successive faunules making up the total fauna occupying the Hamilton formation of central New York. In it account is given of the species obtained in a careful and full examination of every foot of the section from the top of the Onondaga (Corniferous) limestone to the base of the Tully limestone, both of which are well marked in the Cayuga Lake section, thus constituting definite limits for the Hamilton formation of this particular region.

All the fossiliferous zones (seventy-six in number) were examined, and upon analysis of the faunules of each zone those which were so closely alike as to signify practically the same set of species, associated in the same biological equilibrium of relative abundance, were grouped together, constituting in all twenty-five separate faunules. These may properly be described as the faunules of the twenty-five successive hemeræ into which the Hamilton epoch of this section may be distinguished by its fossils. These faunules are associated with more or less definite changes in the character of the sediments in which they were buried. The separate divisions of the formation thus recognized by slight differences in faunal composition as well as in lithologic constitution may be called zones. The Hamilton formation, its fauna, and the particular section here studied are well known to paleontologists, so that the species can be easily recognized and listed. In making the collections special attention was given to the discovery of the relative abundance of the species found associated together in each rock stratum. Direction was given to collect the fossils as near as possible in the proportion of numbers presented by the natural occurrence in the rocks. Instead of attempting to dis-

cover rare species, the purpose was to let the preserved collection represent as perfectly as possible the natural proportion of association. The working up of the collection was made to express this natural proportion expressed by the species.

The identification of species is probably always affected more or less by personal judgment. In order to make the statistics of the greatest relative value, therefore, no attempt was made to criticise these personal elements in the author; and while it is probable that another worker dealing with the same specimens would not reach absolutely identical listing of species, it is probable that the errors, if any, from inaccuracy of specific identification are so small relatively as to not disturb the statistical value of the facts recorded. Further and more exhaustive search, also, may be expected to considerably modify the statistics here given; but even this fact does not detract from the value of those here recorded. The more refined the analyses become the more perfect will be our knowledge of faunal compositions. The present investigation is a step in the direction of attaining the fullest possible perfection in recording faunal statistics, and in making these faunal analyses as perfect as they can be made, toward which end the contributions of many workers will be needed. With such statistics in hand we may hope to understand better the laws of evolution as affected by and related to the varying conditions of environment and time.

It will be noticed that the thickness of the Hamilton, as measured by Prosser in the Ithaca well, is 1,224 feet—that is, between the top of the Onondaga (Corniferous) limestone and the base of the Tully limestone. The exact thickness was not determined by the author. The reason for this is that the great thickness and similarity in the character of the rock of Zones B and C made the accurate measurement of these zones impossible. This is shown in the section (fig. 2) by broken lines. Nevertheless it is believed that the discrepancy does not affect the accuracy of the succession of the fossiliferous zones recorded in this paper. Attention is here called to the fact in order to show how difficult it is to make exact correlation for short distances when the sediments are of similar composition and structure and the general fauna is the same. For the purpose of ascertaining the exact thickness of each zone, a continuous section is necessary, but a long series of shorter sections, where the dip is slight, offers the advantage of a greater number of exposures of the rocks for the collection of the fossils. It is hoped that the present sample of what can be done in the way of an historical study of a fossil fauna may inspire other workers to make similar studies of the rocks in their own localities for comparison and demonstration of the geographical as well as the geological modifications of fossil faunas.

PREFACE.

The material for this study was collected during three months of the summer of 1899 and during May, 1901, from the Hamilton formation exposed along the east side of Lake Cayuga and the west side of Seneca Lake. Commencing at the Onondaga (Corniferous) limestone, an attempt was made to collect the complete faunule from each zone throughout the entire Hamilton formation up to the Tully limestone.

In the identification of the fossils the principle has been followed that unless absolutely necessary no new species or varieties should be described, but that all doubtful specimens should be referred to species already figured.

The writer is indebted to Prof. H. S. Williams for many helpful suggestions concerning methods of work.

A STUDY OF THE FAUNA OF THE HAMILTON FORMATION OF THE CAYUGA LAKE SECTION IN CENTRAL NEW YORK.

By HERDMAN FITZGERALD CLELAND.

CHAPTER I.

GENERAL DESCRIPTION AND GENERAL GEOLOGY OF CAYUGA LAKE REGION.

GENERAL DESCRIPTION.

The region studied is about 70 miles west of the center of New York State, and extends across about one-third of the State from north to south, the center of the region being nearly in the center of the north-south line. Cayuga Lake, along the east side of which the material for this study was collected, is one of the so-called "finger lakes" of the State, and, with its outlet, forms the boundary between Seneca and Cayuga counties.

In the western two-thirds of the State the strata strike in an east-west direction and dip to the south. Because of this southerly dip it is possible for one to see a large part of the Paleozoic section in a comparatively short distance in passing from north to south. The Cayuga Lake region itself embraces all of the formations between and including the Salina and the Ithaca.

This region is overlain by glacial drift, which hides the rock, except where worn away by erosion. Almost every stream that enters the lake has cut a deep gorge through the drift and into the shale, making excellent exposures. The gorges thus formed often have banks of shale 100 feet or more in height. In all of these creeks there are from one to four falls, the highest of which are caused by four strata of limestone and the hard sandstones or flags of the Portage. A description of Shurger Glen, about 5 miles from the south end of the lake, will, in a general way, answer for all the streams flowing into the lake, the only difference being that the streams farther down the lake do not flow over the Tully limestone, Portage sandstone, etc.,

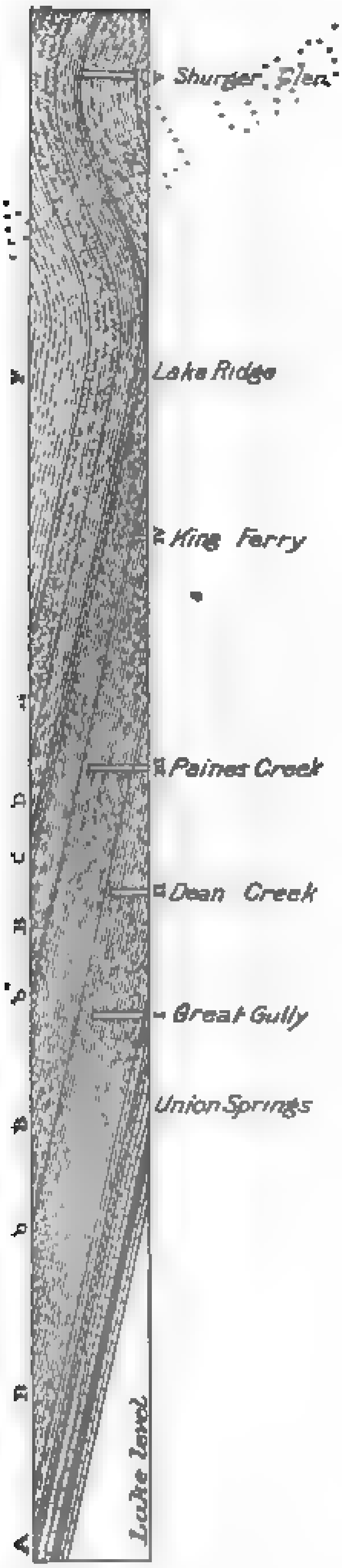

FIG. 1.—Cayuga Lake section. A, Marcellus shale; B, Hamilton formation; b', limestone of zone D; b'', Encrinal beds; C, Tully limestone; D, Genesee shale; E, Portage; F, Ithaca.

and consequently have fewer falls. In Shurger Glen there are four sets of falls. The first, nearest the lake, about 30 feet high, is caused by the Encrinal beds (limestone); the second, by a hard shale; the third, by the Tully limestone; and the fourth, by the Portage. In Paines Creek near Aurora the Tully and Portage have been eroded away, leaving the Encrinal and the hard calcareous shales of Zone D at Moonshine to form the fall. In the creeks at Farleys the upper hard limestone capping the Marcellus shale, Zone B, forms the falls.

GENERAL GEOLOGY.

The lake section.—In traveling from the village of Cayuga to Ithaca one passes over and can collect from, (1) the Eurypterus beds (Rondout limestone or Waterlime), (2) black gypsum (probably Rondout limestone), (3) Stromatopora beds (Manlius limestone[a]), (4) Oriskany sandstone (this formation has a maximum thickness here of 4 feet 10 inches and thins out to nothing in less than a mile, leaving the Onondaga (Corniferous) in contact with the Lower Helderberg), (5) Onondaga limestone, (6) Marcellus shales, (7) Hamilton shales and impure limestones, (8) Tully limestone, (9) Genesee shale, (10) Portage shales and sandstones. (See fig. 1.)

For the purpose of this paper it will not be necessary to speak more fully of any of the formations mentioned above, with the exception of the Hamilton.

Hamilton formation.—The description of the shales and limestones of the Hamilton formation is given in detail in the description of the different zones which make up this formation. In general it may be said that the Marcellus shales immediately above the Onondaga limestone (where they are very black and fine) alternate with eight or ten layers of impure limestone for a distance of 10 feet. The shale becomes harder and sandy toward the top and closes with a very hard, impure limestone. The Marcellus, as

[a] Memoir New York Mus., Vol. III, No. 3, Oct., 1900, pp. 8-9

shown by a recent well boring, is 81 feet thick. Above this limestone are the shales of Zone C, several hundred feet thick, which are very soft, with occasionally a harder, more calcareous, or sandy layer, and several courses of concretions. The thick, impure limestone or hard calcareous shale, Zone D, which overlies the soft shales of Zone C, is very marked because of its hardness and richness in fossils. Immediately above this zone and in contact with it is a layer of shale 50 feet thick, as fine and black in the lower part as the Marcellus shale. Above this the calcareous Hamilton shales continue to the Encrinal, becoming somewhat harder as the Encrinal is approached.

Encrinal bed.—The Encrinal is a crystalline limestone about 1½ feet thick. Above this the Upper Hamilton or Moscow shales extend to the Tully limestone. The Upper Hamilton shales vary greatly in hardness and faunal combination.

Concretionary layers.—Concretions appear not far from the Encrinal beds. These concretionary layers are at first shaly, but in the Cayuga Lake section become progresssvely more calcareous as the Tully limestone is approached.

The persistence of the concretionary layers was observed for some distance. One course, which contained *Leiorhynchus laura* and *Orbiculoidea lodiensis media* (Zone V), was observed at Shurger Glen, Lake Ridge, and King Ferry, a distance of 12 miles. These concretions could not be identified in the Seneca Lake section. The thin layer of limestone under the Tully, included in Zone Y, was noted at these places also. Both the limestone layers and the fossils of Zone Y were wanting in the Seneca Lake region. Zone H at King Ferry, containing small upright concretions, with a characteristic fauna, was found also in Paines Creek, 5 miles north. The extent of the Encrinal beds and hard calcareous shales of Zone D is spoken of in another place (pp. 82–83).

Jointing.—The jointing of the rock in this whole region is exceptionally well developed. The joint planes have a direction of N. 20°–30° W. and S. 5°–15° E., and are almost vertical. (See Pl. II.) This jointing accounts, in large measure, for the perpendicular faces of the falls and cliffs which are so noticeable in this region.

Tully fold.—As one goes up the lake from Union Springs the general dip of the rock to the south is very noticeable, the different strata continuing for some distance and then disappearing under the lake. Using the Tully as a reference plane,[a] it was found that from King Ferry to Lake Ridge the strata descend about 45 feet to the mile. To the south the Tully limestone takes a horizontal position and remains a little above lake level for about 3 miles. It there rises into an arch over 6 miles long, with its highest point at least 235 feet above the lake. From this point south the dip is very rapid, varying from a

[a] Dip of rocks in central New York, by S G Williams: Am Jour. Sci., 3d series, Vol XXVI, 1883, pp. 303–305.

maximum of 400 feet to the mile, the average being 110 feet. Vanuxem[a] noticed this fold, and explained it as an apparent but not a real fold, reasoning that since the strata dipped southward the bend of the lake to the east would cut into the strata and give the appearance of a fold. The direction and amount of dip of the strata are such that the bend in the lake could not alone have produced such an arch, although it undoubtedly had some effect. The folds along Seneca Lake and the fault in the outlet of Keuka Lake, which are in a west-of-north direction from the Cayuga Lake arch, point to the explanation that this whole region suffered a lateral pressure sufficient to crumple the strata, thus forming a long fold of which the arch at Cayuga Lake and the undulations in the strata at Seneca Lake are a part. The impure limestone of Zone D is so folded that the creek cuts through it twice before it reaches the fall at Moonshine. In Big Gully Creek the limestone which caps the Marcellus shales is cut through by the stream before it reaches the fall; it also makes a fold to the south, forming falls in two small streams.

The fact that the region is not faulted, that the folds are easily seen, and that the creeks cut through the glacial drift into the shales, makes the collecting especially easy, and reduces to the minimum the liability to error in locating the horizons in different sections. The difficulties in the way of making accurate measurements with the instruments at hand were such that all measurements given are only approximate.

[a] Geology of New York. Survey of the third district, 1842.

JOINTING IN UPPER HAMILTON SHALE AT SHURGER GLEN

The stream falls over Tully limestone

CHAPTER II.

HISTORY OF THE HAMILTON FORMATION.

McClure.—The first American geologist, William McClure, published a geological map of the United States in the Transactions of the American Philosophical Society in 1809. In this map "he struck out the ground outline of geographical geology."[a] The line separating the "Primitive rocks" from the "Floetz, or secondary," followed the Oneida and Mohawk rivers of New York to the Hudson River. All the country between the Alleghenies and a line running north and south through the western boundary of Arkansas, with the exception of a narrow strip along the Gulf of Mexico, is marked as Floetz, or secondary, and embraces, in a general way, the formations from the Silurian to the Pleistocene.[b]

Eaton.—Amos Eaton after, for that time, considerable travel and observation, published An Index to the Geology of the Northern States in 1820, and later, under the patronage of Stephen Van Rensellaer, made a geological survey of the district adjoining the Erie Canal. These observations he published in 1824.[c]

Werner.—These pioneers in geology were followers of Werner, who attempted to correlate the strata in America with those of Europe as described by the German geologist. As Werner depended entirely upon the lithological character of the strata for his correlations (the value of fossils in correlation not being known at that time) great confusion resulted.

Early attempts at correlation.—Since the Old Red sandstone of England is a conspicuous formation, both McClure and Eaton took it as a convenient reference plane. Eaton first correlated it with the Catskill sandstone (Devonian) and the Triassic sandstone of the Connecticut River. McClure considered the Red sandstone of the Medina group (Silurian) and the Triassic sandstone of the Connecticut River as the equivalent of the Old Red sandstone of Europe. In 1824 Eaton concluded that "the 'Old Red sandstone' rests on the Metalliferous graywacke [Utica and Hudson River group] and underlies the Millstone grit" [Oneida conglomerate of the Medina group]; that is, that the Old Red sandstone (Devonian) should be correlated with a portion of the Medina sandstone, thus placing the greater part of the Upper Silurian and the Devonian in the Carboniferous.

Search for coal.—After the decision was reached that the Red sandstone of the Medina was equivalent to the Old Red sandstone (Devo-

[a] Index to the Geology of the Northern States, by Amos Eaton, 1820, p. viii.
[b] Trans. Am. Philos. Soc., Vol. VI, 1809, pp. 411-428.
[c] Geological and Agricultural Survey of the District adjoining the Erie Canal.

nian) of England which underlies the coal, Eaton expected to find coal in some of the formations in the southern part of the State, and advised the people who lived south of the Medina sandstone to dig for coal wherever there were any indications. Eaton's belief that what we now know to be the Devonian was Carboniferous was strengthened by the finding of thin layers of carbonaceous matter in what, from the localities mentioned, must have been the Marcellus and Genesee shales. This coal in very thin layers is occasionally found in these horizons. Because of this advice a great deal of money was wasted in a vain search for coal.

The different formations of the Devonian were not distinguished by Eaton. The "third graywacke" or "pyritiferous rocks" included all the formations above the Onondaga. His description of this "rock" as a calcareous or siliceous gray rock, with aluminous cement, either slaty or in blocks and rich in fossils, and the localities, the end of Cayuga Lake and the south shore of Lake Erie, between its eastern extension and Sturgeon Point, does not distinguish between the different formations. The Hamilton in the Cayuga Lake locality was not included, as is shown by the fact that the Tully was mistaken for the Onondaga (Corniferous) limestone.

Conrad and Hall.—In 1837 Conrad gave as the object of the New York State survey the stratigraphical and economic study of the various rock formations. The attention of his assistants was directed to the "mineral and fossil contents" of the rock, as the fossils "serve to determine with much accuracy the geological age and character of the strata."

In 1838 Hall considered the rocks of western New York as belonging to the Devonian and Carboniferous. His reason for believing this, he says, rested chiefly on the study of the organic remains, especially of the vertical distribution of the trilobite.[a]

Conrad, in the same report, concluded that the rocks of New York, with the exception of the Catskill, terminated with the Upper Ludlow rocks of Murchison [Upper Silurian].

In the section along the Genesee River, given in the same report, the shales between York and Mount Morris are marked as "limestone shales." This was one of the first attempts to separate the rocks above the Onondaga (Corniferous) in New York State into finer divisions.

In the Fourth Annual Report, 1840, Hall compared the fossils from the New York strata with those of England and correlated the Catskill with the Old Red sandstone [Devonian] of England; the Chemung to Moscow shales [Upper Hamilton], inclusive, with the Upper Ludlow rocks [Upper Silurian]; and the Ludlowville [Lower Hamilton] and Marcellus shales with the Lower Ludlow rocks [Upper Silurian], and adopted the name Ludlowville to show this correlation.

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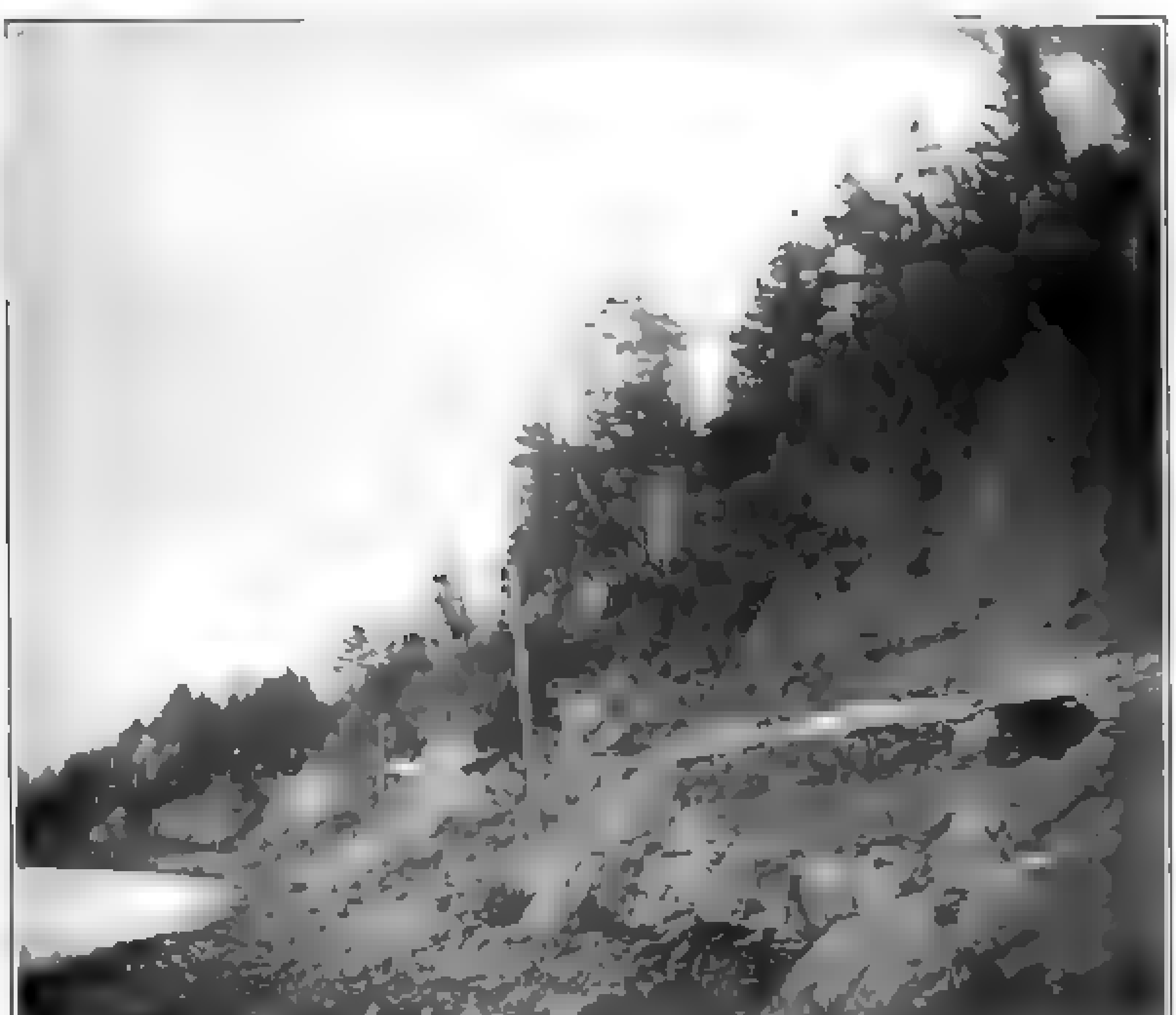
[a] Second Ann. Rept. New York Geol. Survey, 1838, p. 291.

A. TULLY LIMESTONE, SOUTH OF SHURGER GLEN.



B. ENCRINAL BED SOUTH OF SHURGER GLEN, SHOWING DIP TO THE SOUTH.

The report of 1841 placed the Hamilton (called Sherburn group and shales near Apulia) and Marcellus (called Black shale) in the Aymestry [Upper Silurian]. According to this correlation the "Lower Ludlow rock" closed with the Onondaga (Corniferous) limestone.

Verneuil's correlation.—In his concluding remarks on Verneuil's Parallelism of the Paleozoic Deposits of America with those of Europe,[a] Hall says that the "line of demarcation between the Devonian and Silurian is at the base of the Upper Helderberg or at the bottom of the Schoharie grit. Verneuil proposed to unite the Marcellus shale, Hamilton shale, Tully limestone, and Genesee shale in one division, and make the Portage and Chemung the second of this period. He correlated the Chemung, Portage, Genesee, Tully, and Hamilton with the formations of Eifel and Devonshire; the Marcellus with the shales of Wissenbach in Nassau.

Renevier's correlation.—In the second edition, 1896, of the Tableau des Terrains Sédimentaires formés pendant des Époques de la Phase Organique du Globe Terrestre, by Professor Renevier, the Marcellus and Hamilton are taken together and considered to have been deposited at the same time as the *Tentaculites* shales (lower part) of Thuringia and Bohemia, Wissenbacher slates, and the schists "à Phacops Potieri de Bretagne."

Williams's correlation.—The line separating the Meso- and Eo-Devonian in America was determined by Prof. H. S. Williams to be at the base of the Tully limestone. Previously the Tully had been included in the Meso-Devonian. The reason for this correlation is as follows:[b]

> The conclusions we draw from this study of the faunas of the Cuboides zone and the Tully limestone are that within narrow limits, geologically speaking, the point in the European time scale, represented by the beginning of the deposition of the Cuboides Schichten of Aix la Chapelle, etc., is represented in the New York sections by the Tully limestone, and, second, that the representative of the fauna of the Cuboides zone of Europe is seen in New York not only in the Tully limestone, but in the shaly strata for several hundred feet above. Therefore, if we wish to express precise correlation in our classification of American rocks, the line between Middle and Upper Devonian formations should be drawn at the base of the Tully limestone, to correspond with the usage of French, Belgian, German, and Russian geologists, who include Frasnein, Cuboides Schichten, and correlated zones in the Upper Devonian.

The Meso-Devonian must therefore be considered as bounded above by the Tully and below by the Onondaga (Corniferous).

South American Hamilton.—The sandstone of Erere in Brazil, a portion of the Huamampampa sandstone of Bolivia, and a portion of the formations of the Jachel River in central Argentina are correlated with the New York Hamilton. These correlations were determined chiefly by the presence of *Vitulina pustulosa* and *Tropidoleptus carinatus.*

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[a] Am. Jour. Sci., 2d series, Vol. V, pp. 176-183, 356-370; Vol. VII, pp. 45-51, 218-231.

[b] Williams, Bull. Geol. Soc. America, Vol. I, 1890, pp. 481-500.

CHAPTER III.

DESCRIPTIONS OF THE FOSSILIFEROUS ZONES.

The Hamilton formation, including the Marcellus shales, is in this region, as shown by the Ithaca well section, 1,224 feet thick.[a] It is bounded above by the Tully and below by the Onondaga (Corniferous) limestone.

The Cayuga Lake section has been divided into twenty-five zones, each zone having been determined by its contained fauna. When, in working up the section, there seemed to be a change in the fauna or the character of the rock, a provisional division was made, the total number of such divisions being seventy-six. Later, in working up the material in the laboratory, it was found necessary to combine many of these divisions, reducing the number to twenty-five.

The name of each zone is the name of the group, genus, or species which seems especially characteristic of the faunule of that zone. The name chosen is not necessarily that of the most abundant species unless that species is, as far as our present knowledge goes, associated with a definite group of fossils. For example, the three *Leiorhynchus* zones have a faunal resemblance which can not be mistaken, although in the first *Leiorhynchus* zone *Leiorhynchus limitare* is the characteristic species, while in the other two zones the species is *Leiorhynchus laura*. It is also true, that *Leiorhynchus laura* may be associated with an abundance of *Orbiculoidea lodiensis media*, as in Zone V. In the first and second *Ambocœlia umbonata* zones a group of species occurs which is often found associated together when *Ambocœlia umbonata* is abundant. In every zone the fauna is more or less modified by species from lower zones continuing on, and by local conditions, but the essential character of the fauna is determined by the environmental conditions.

A. HAMILTON-ONONDAGA (CORNIFEROUS) ZONE.

Stratigraphy.—This faunule at Cayuga Lake was found in a layer 2 inches thick, almost completely made up of poorly preserved fossils. The shale which held them together was composed of finely comminuted fossils, principally tentaculites. Between this zone and the Onondaga (Corniferous) limestone are eight or ten alternations of impure limestones and fine sooty shale, aggregating 12 feet (see

[a] Prosser, Am. Geologist, Vol. VI, 1890, pp. 199-211.

ALTERNATION OF IMPURE LIMESTONES AND SHALES ABOVE THE ONONDAGA BEDS AT UNION SPRINGS.

Zone A. 1, Goniatite bed; 2, impure limestones and shales; 3, Onondaga limestone

Pl. IV). Two feet below this zone is a limestone layer (Goniatite limestone), which is purer than any of the layers between it and the

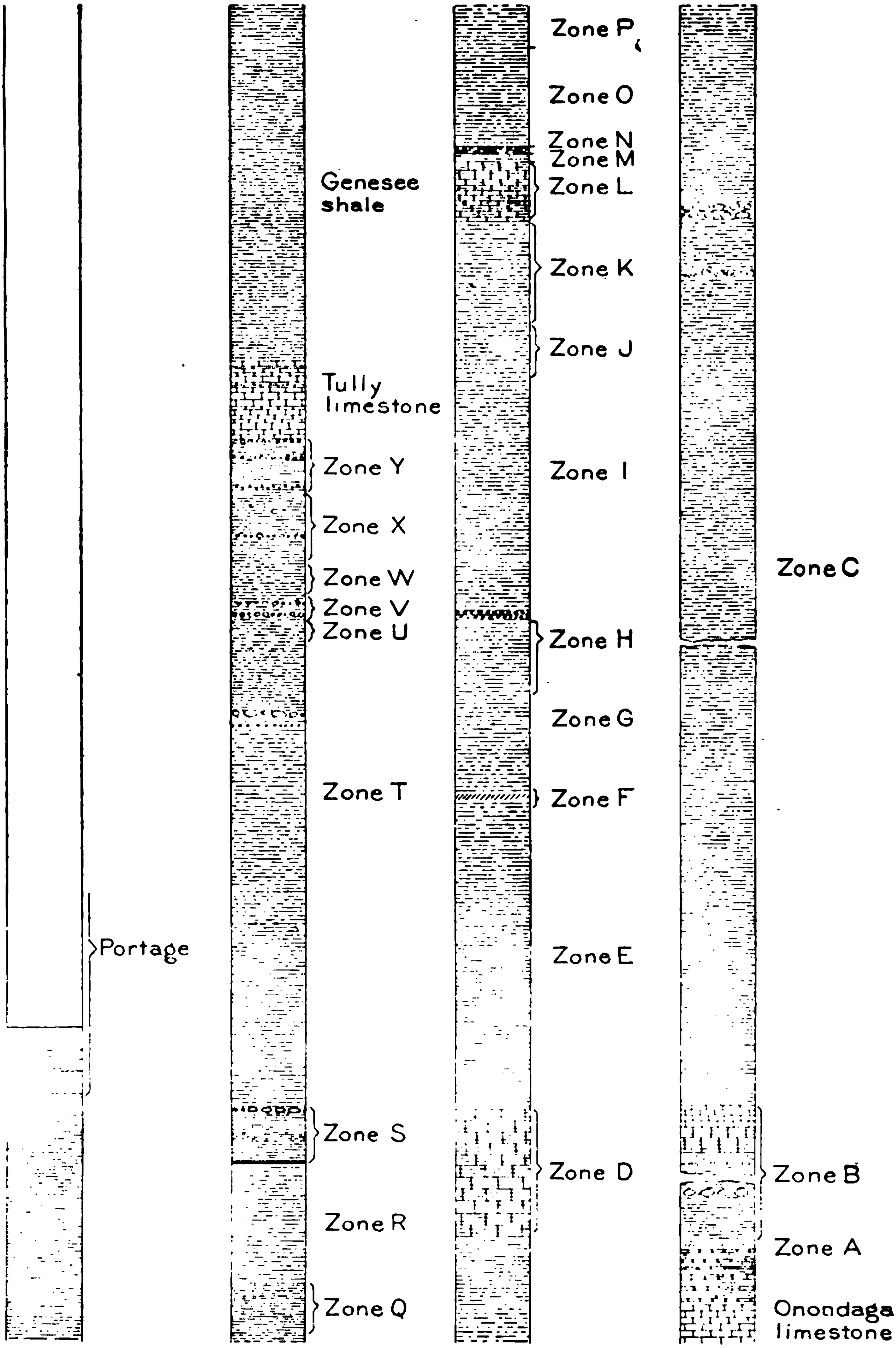

FIG. 2 —Zones in Cayuga Lake section.

Onondaga limestone. Below and above Zone A the shale is very rich in *Styliola fissurella* and *Tentaculites*.

Faunule.—The faunule of this zone is a mixture of Onondaga and Hamilton species, of which Brachiopoda make up the greater part. It contains *Chonetes mucronatus*, *Ambocœlia umbonata*, *Tropidoleptus carinatus*, and other Hamilton species, together with *Spirifer macrus*, *Anoplotheca camilla*, *Chonetes lineatus*, and *Phacops cristata* var. *pipa* of the Onondaga. The absence of *Chonetes coronatus* and *Tropidoleptus carinatus* below this level (12 feet above the Onondaga) shows that the Hamilton must have been developed elsewhere for a long period of time before the deposition of this zone. The fauna is remarkable in that it is not a transition between the Onondaga and Marcellus, but between the Onondaga and Hamilton. Although all the species mentioned, with the exception of *Chonetes coronatus*, have been found in the Marcellus, they are not characteristic of that horizon, but most of them are the common fossils of richly fossiliferous Hamilton zones.

A faunule of similar composition was found in an impure limestone 9 feet above the Onondaga limestone, at Livonia. This faunule contained *Anoplotheca camilla* associated with Hamilton and Onondaga fossils.[a]

Locality.—South of Union Springs, 12 feet above the Onondaga. Layer of gray shale 2 inches thick.

B. FIRST LEIORHYNCHUS ZONE (Marcellus shale).

Stratigraphy.—In the first creek south of Great Gully Creek, in the bed of the stream near the mouth, and in the shale along the lake shore south of this, flattened spherical concretions occur, many being 3 feet in horizontal and 1½ feet in vertical diameter. No fossils were found in them.

The Marcellus shale closes with a hard, impure limestone, 4½ feet thick, which is very noticeable in the creeks in this vicinity, since it forms falls wherever it occurs. It is important in this section, because it makes a distinct line between the shales of the first and second *Leiorhynchus* zones.

With the exception of 2 feet of bituminous shales immediately above Zone A, the Marcellus shales between Union Springs and Great Gully Creek are covered. It is impossible to make an accurate estimate of the thickness of this zone because of the folding of the strata in this region. At Union Springs the Onondaga is folded, and at Great Gully Creek the limestone layer of the Marcellus is so folded that it forms two falls. This same stratum folds to the south, making the rise of ground south of Levanna. The well boring recently made at Ithaca (1900) shows the fine black shale of the Marcellus to be 81 feet thick. It is probable, therefore, that the total thickness is between 80 and 100 feet.

Faunule.—The faunal combination of this zone does not differ materially from that of the second and third *Leiorhynchus* zones with

[a] J. M. Clarke, Forty-seventh Ann. Rept. N. Y. State Mus., pp. 327-352.

the exception of the replacement of *L. limitare* by *L. laura*. In the lower portion of the zone the shale is extremely fine, and the abundance of *Styliola* and *Tentaculites* much greater than in the other *Leiorhynchus* zones. The shales become coarser and the fossils more abundant (with the exception of *Tentaculites* and *Styliola*) as Zone C is approached. The fauna of the upper portion is especially rich in *Orthoceratites*. About 2 feet below the limestone is a nodular layer extremely rich in *Leiorhynchus limitare* in an excellent state of preservation. The shale for 2½ feet below the limestone is very calcareous and coarse, but still contains *L. limitare* and its characteristic fauna.

A *Leiorhynchus* fauna has approximately the following composition:

Leiorhynchus { laura,
limitare.
Chonetes { mucronatus,
scitulus,
lepidus.
(Orbiculoidea media).
Strophalosia truncata.
Lunulicardium fragile.
Leiopoteria lævis.
Nuculites { triqueter,
oblongatus.
Nucula corbuliformis.
Styliola fissurella.
Tentaculites.
Phacops rana.

Locality.—Near the mouth of the creeks between Levanna and Farleys. The best exposure for the upper portion is in Great Gully Creek; for the lower, the quarries south of Union Springs.

C. SECOND LEIORHYNCHUS ZONE.

Stratigraphy.—This zone is quite uniform in its lithological and faunal characters with the exception of one layer of dark calcareous shale about 15 feet above the Marcellus shale, which contains a greater number of *Phacops rana* and *Ambocœlia umbonata* than is usual elsewhere in the section. As a rule the shale is fine and seldom contains more than eight or nine species to each 5 feet. Two courses of concretions occur 70 feet below Zone D. Occasionally a harder layer occurs; but, with the exception mentioned, the species do not change with this slight change in sedimentation. The lower and upper portions of this zone were worked more carefully than the middle portion.

Faunule.—This zone, which is several hundred feet thick, is very poor in fossils. The faunule is one which usually occurs in the fine shales of the Hamilton stage where the conditions were not favorable to a rich Hamilton faunule. The make-up of the fauna is given under Zone B. This same faunule is reported from the Livonia section.

Localities.—Paines Creek, south of Aurora, from Moonshine Falls to the lake; Deans Creek, north of Aurora, from Goulds Falls to the lake; Great Gully Creek, south of Union Spring, to the Marcellus shale. It is also finely developed in the Seneca Lake section.

D. FIRST TEREBRATULA ZONE (Basal limestone of Clarke).

Stratigraphy.—Because of its hardness, compared with the soft shales above and below, this zone forms a fall in all of the creeks

where it appears. Moonshine Falls, on Paines Creek, and the fall in Deans Creek, on the farm of James Gould, are from 30 to 40 feet high. The rock is a hard calcareous shale, almost an impure limestone. The fauna as well as the lithological character separates this zone sharply from the shales above and below. It is 25 feet thick in Paines Creek.

Faunule.—The genera of this section are not, by any means, the most common fossils in this zone; but since they are associated with a peculiar combination of species, both here and at Eighteenmile Creek, the name *Terebratula* has been used to designate that combination. The combination of species spoken of above is *Cryptonella planirostris*, *C. rectirostris*, *Meristella haskinsi*, *Eunella lincklæni*, *Spirifer divaricatus*, *Vitulina pustulosa*, and in the Encrinal, in addition or by substitution, *Centronella impressa*.

This is the first and only zone in which *Heliophyllum halli* appeared in any numbers. The locality was, however, especially favorable for collecting, on account of the great area of the zone exposed by the folding of the strata and the consequent wearing away of the soft upper shales in several places by the action of the water. One specimen of *H. confluens* was obtained from the Encrinal beds at Black Rock, on Paines Creek, and one specimen of *H. halli* from a doubtful locality in the Upper Hamilton. With these exceptions no specimens of this genus were found above or below Zone D. *Vitulina pustulosa* is common, and was found in the same abundance in the Encrinal beds, but not elsewhere in the section.

The shale of this zone is extremely fossiliferous. The total number of species found was 84; of these, 32 are Pelecypoda, 33 Brachiopoda, 4 Gasteropoda, 3 trilobites, 3 corals.

Localities.—Paines and Deans creeks on the east side of Cayuga Lake; Slate Rock Run on west side of Seneca Lake. D. F. Lincoln[a] reports it from Bentons Run, west side of Seneca Lake; north of Days Landing; Reeders Creek; West Fayette station; 1 mile west of West Bearytown; 1 mile southeast of Bearytown; Big Hollow Creek east of Romulus. Clarke reports it from Canandaigua Lake and Flint Creek.

NOTE.—This zone is well exposed in Slate Rock Run on the west side of Seneca Lake. In this locality it is 15 feet thick and contains a faunule very similar to that of the Cayuga Lake region. The principal difference noted was the greater abundance of cyathophylloid and Favosite corals. The common fossils of this zone in Slate Rock Run are:

Heliophyllum halli.	Eunella lincklæni.
Cystophylum americanum.	Rhipidomella vanuxemi.
Favosites.	Crinoid stems.
Chonetes mucronatus.	Stropheodonta inæquistriata.

[a] Ann. Rept. State Geol. New York, 1884.

E. THIRD LEIORHYNCHUS ZONE.

Faunule.—Immediately above the calcareous shales of Zone D occur 55 or 60 feet of very fine black shales which are extremely barren of fossils. This is especially true of the lower 25 feet, in which but ten species were found, the complete faunule being twenty-seven species. *Styliola fissurella* and ostracods occur abundantly in thin layers, but in the body of the shale they are seldom seen. With few exceptions the ostracods and styliolæ do not reappear in this section above this zone and never again in abundance.

The change of sedimentation from a firm calcareous to a fine black mud was evidently a condition unfavorable to the rich faunule of Zone D, and either (1) it was replaced by migration of a faunule similar (recurrent) to that of the shales below Zone D or, what seems probable, (2) the species found in Zone E, which were inconspicuous in the faunule of Zone D, lived on while their less adaptable neighbors perished. The shales of this zone contain no brachiopods and only three species of pelecypods—and they are rare—which are not found in Zone C. They contain one brachiopod and two pelecypods which are not found in Zone D. The faunule of this zone bears a strong resemblance to the "recurrent fauna" of Ontario County.[a]

Localities.—Above and in contact with Zone D in Paines and Deans creeks; on Cayuga Lake, and in the Seneca Lake section.

NOTE.—The shales of this zone are of this same character west of Seneca Lake. The resembance to the Marcellus is so strong that Mr. Berlin H. Wright[b] called the shales of this zone in the Kashong Creek section "Marcellus." The lithological character and the faunule are both very much like that of the Marcellus, with the exception of *Leiorhynchus limitare*, which the writer did not find in the Kashong section.

F. MICHELINIA ZONE (Provisionally).

Stratigraphy.—This zone is not separated from the lower shales by any distinct line, the division being made by the abundance of the fossils and change in species. It terminates in a more calcareous layer 4 inches thick, in which *Michelinia stylopora* is common. The number of species is not great except by comparison with the zones above and below. Compared with E and G the species are in the ratio (E) 29: (F) 50: (G) 23. The thickness of the zones, in feet, is in the ratio (E) 55: (F) 5: (G) 18.

Faunule.—The only common species are *Tropidoleptus carinatus*, *Nucula corbuliformis*, *Cypricardella bellistriata*, *Michelinia stylopora*, and crinoid stems. *Grammysia constricta*, *Ceratopora dichotoma*, and *Michelinia* appear for the first time. *Tropidoleptus carinatus* is very common, but of small size.

Location.—Paines Creek, 60 feet above Moonshine Falls. Five feet thick.

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[a] J. M. Clarke, Ann. Rept. State Geol. New York, 1884, pp. 9-22.
[b] Thirty-fifth Ann. Rept. New York State Mus., 1882, pp. 195-206.

G. CHONETES VICINUS ZONE.

Stratigraphy.—This zone comprises the firm shales below the falls nearest the lake, at King Ferry, and the upper portion of the section on Paines Creek; 23 species; 18 feet thick.

Faunule.—*Chonetes vicinus*, which appeared in Zone F, became very abundant and of large size in this zone. *Tropidoleptus carinatus* is common. *Lunulicardium fragile* and *Cypricardella bellistriata* are found occasionally. The shales are not so barren as the small number of species would indicate, although they are by no means rich in fossils.

Locality.—King Ferry and Paines Creek.

NOTE.—Later investigation shows that the name *Chonetes vicinus* does not express a faunal combination. The zone is a distinct one at King Ferry, but is an expression of peculiar local conditions rather than a normal faunule. This zone was not found in the Kashong Creek section.

H. TRANSITION ZONE.

This zone does not have a distinctive faunule and is probably a transition between Zones G and I.

Locality.—King Ferry, N. Y.

I. FIRST CYPRICARDELLA BELLISTRIATA-ATHYRIS SPIRIFEROIDES ZONE.

Faunule.—The abundance of *Cypricardella bellistriata*, *Athyris spiriferoides*, and *Spirifer pennatus* is characteristic of this faunule. The relative abundance of all of the species in the zone changes somewhat from the bottom to the top. *Tropidoleptus* is common in the lower third, rare in the middle, and common again in the upper third. *Pholidostrophia iowaensis* appears for the first time in the lower third and was not common elsewhere in the section.

Location.—King Ferry, above the first falls; 47 feet thick.

NOTE.—The faunule of the shale 25 feet below the Encrinal beds, 19 feet thick in the Kashong Creek (Seneca Lake) section, bears a stronger resemblance to Zones I and K than to J, but the faunule as a whole has a different facies. It resembles I in the abundance of *Tropidoleptus carinatus* CA, *Chonetes mucronatus* CA (instead of *C. vicinus*), and *Spirifer pennatus.* It differs in the scarcity of *Cypricardella bellistriata* and *A. spiriferoides* and in the abundance of Bryozoa and crinoid stems. The 25 feet of shale immediately underlying the Encrinal is very poor in fossils, the faunal combination of which is not plain.

J. TELLINOPSIS ZONE.

Faunule.—This faunule differs from that of Zones K and I in its paucity of spirifers, *Athyris spiriferoides* and *Tropidoleptus carinatus*

and in the abundance of *Ambocœlia umbonata*, *Tellinopsis subemarginata*, and *Modiomorpha*. There is one thin layer of *Ambocœlia umbonata* and *Chonetes scitulus*. The shale of Zone J is finer than that of Zone K and more fossiliferous.

Locality.—King Ferry, 20 feet below the Encrinal beds; 10 feet thick.

K. SECOND CYPRICARDELLA BELLISTRIATA-ATHYRIS SPIRIFEROIDES ZONE.

Faunule.—This faunule is a recurrence of Zone I, with slight modifications. The numerous individuals of the upper third of Zone J are the characteristic fossils of K with the exception of *Chonetes vicinus*. Other species of *Chonetes* are common and balance the loss of *C. vicinus*. The abundant species of Zone I are most common in Zone K. This zone resembles Zone X of the Upper Hamilton, except that in Zone X *Leiorhynchus laura* continues from Zone V.

Locality.—King Ferry, extending down from the Encrinal for 22 feet.

L. SECOND TEREBRATULA ZONE (ENCRINAL BEDS).[a]

Stratigraphy.—The Encrinal bed includes 8 feet of calcareous shales, impure limestone, and 1½ feet of crystalline limestone, with an abundance of crinoid stems in the upper part.

Faunule.—Of the 47 species occurring in this bed, 14 are from the crystalline limestone. No fossils are abundant. Of the 7 species which are common 3 are distinctive; *Vitulina pustulosa* is found also in D; *Centronella impressa* occurs here for the first time and does not appear again; *Eunella lincklæni* is found also in D and Y; *Spirifer divaricatus*, one fragment, is found in D; *Nucleospira concinna* is rarely found in the section, and *Spirifer granulosus* reappears here. (For discussion of Encrinal see Chapter V.)

Locality.—This zone, called also the Encrinal bed, includes the crystalline Encrinal beds and impure limestone and shales, 8 feet in all, found in the creeks between Shurger Glen and Aurora.

M. ORTHONOTA ZONE.

Faunule.—This zone differs decidedly from that above and below in the composition of its fauna. A glance at the accompanying table (Pl. V) will show the distinctness of this zone. The common Pelecypoda are *Phthonia nodicostata*, *Orthonota undulata*, *Prothyris lanceolata*, and *Tellinopsis subemarginata*.

Locality.—Shurger Glen. A rather fine shale 1½ feet thick underlying a harder layer (Zone N) which forms a small falls 2½ feet high a short distance from the fall over the Encrinal.

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[a] Including the genera of Section A; cf. Schuchert: Bull. U. S. Geol. Survey No. 87, p. 124.

N. (TRANSITION ZONE.)

Zone N is a rather hard, limy layer, 6 inches thick, which forms the capping for a falls 2½ feet high. The faunule is not a distinct one. The abundance of *Tropidoleptus carinatus* places it with the zone which follows, while the fewness of *Chonetes* and abundance of crinoid stems and Bryozoa places it with the preceding faunule. It is lithologically distinct, but must be called a transition faunule.

O. CHONETES ZONE.

Faunule.—The abundance of *Chonetes mucronatus* and *C. scitulus* is very noticeable. In a fine shale, 3 inches thick, is an abundance of *Spirifer pennatus* and *Tropidoleptus carinatus.* A hard, argillaceous, sandy layer above this is very rich in *S. pennatus.* This zone is not well marked, and is probably very local.

Locality.—Shurger Glen. Coarse and rather sandy strata overlying the hard layer forming the small fall; 10 feet thick.

P. FIRST AMBOCŒLIA ZONE.

Faunule.—There is little difference between this zone and Zone R except that there is a greater abundance of individuals in the latter. *Ambocœlia umbonata* and *Phacops rana* are abundant and *Pholidops hamiltoniæ* and *Chonetes mucronatus* are common. Pelecypods, with the exception of *Palæoneilo constricta*, are rare. The association of *P. rana* and *A. umbonata* is seen in thin layers throughout the section. (See under *A. umbonata*, Chapter IV.)

Locality.—Twenty feet above the Encrinal beds at Shurger Glen; 5 feet thick.

Q. CHONETES LEPIDUS ZONE (rather barren shales).

Faunule.—The 15 feet of thin shale of which this zone is composed is very barren both in individuals and in species, the upper 5 feet being extremely so. Only 16 species were found in the entire bed; of these 6 species are found in the upper 5 feet and 12 species in the lower 10 feet. In the upper 5 feet *Chonetes lepidus* and *A. umbonata* are the only common fossils.

The conditions in this region during the deposition of these shales were very unfavorable to life. At first the fauna was rather large, but at last the two species mentioned above were almost the only ones that were able to survive. The conditions were not unlike those which existed during the deposition of the muds forming Zone E. The effect of the unfavorable environment is seen in the small size and number of individuals.

Locality.—Shurger Glen. Twenty-five feet above the Encrinal beds and 20 feet below the concretionary layer of Zone S.

R. SECOND AMBOCŒLIA ZONE.

Stratigraphy.—This zone is bounded above by the *Stropheodonta*-Coralline zone and below by fine shale. It is a very marked zone in the Shurger Glen section. Large blocks of shale which have fallen from the cliff are almost completely made up of *Ambocœlia umbonata*, with many *Phacops rana* in an excellent state of preservation.

Faunule.—Besides *A. umbonata* and *P. rana*, *Pholidops hamiltoniæ* and *Palæoneilo constricta* are very common. *Chonetes mucronatus* is often found. A comparison of "the fauna of the *Spirifer consobrinus* fauna, Da" of Grabau[a] with this zone shows that (1) the relative position and (2) the faunule are the same. (See under *Ambocœlia umbonata.*)

Locality.—Shurger Glen and King Ferry, 40 feet above the Encrinal beds. Underlies the concretionary layer of Zone S. Twenty-five feet thick.

NOTE.—A bed with a fauna of this same composition occurs in the Kashong section. The resemblance is so striking that it can not be mistaken. It is about 80 feet above the Encrinal beds in this section and but 40 feet at Shurger Glen. The zones of the two sections may be continuations of the same bed, but there is no evidence to that effect except the character of the faunule and the rock.

S. STROPHEODONTA—CORALLINE ZONE.

Stratigraphy.—This zone includes the lowest concretionary layer in which the concretions are of large size. The concretions are shaly, but the shale in which they are embedded is rather more calcareous than usual. The fossils occur in three or four layers, about 2 or 3 inches thick. In these thin fossiliferous layers the shale weathers into a mud, leaving the fossils conspicuous. In the lower part of the zone occurs a very thin layer composed almost entirely of crinoid joints.

Faunule.—The rarity of *Ambocœlia umbonata* and the abundance of Bryozoa and crinoids, together with *Stropheodonta inæquistriata*, *S. concava*, *Rhipidomella vanuxemi*, and corals in considerable numbers, make this zone distinct from that above and below.

Locality.—Shurger Glen, 60 feet above the Encrinal beds. In a concretionary layer 10 feet thick.

NOTE.—Thin layers containing this faunule commence 40 feet below the Tully at Kashong Creek (Seneca Lake), and occur frequently for 30 feet. The common fossils are:

Spirifer pennatus.	Atrypa reticularis.
Stropheodonta inæquistriata.	Streptelasma rectum.
Stropheodonta concava.	Amplexus sp.?
Stropheodonta junia.	Crinoid stems.

This faunule responded very quickly to certain conditions, as is shown by its frequent occurrence in the Seneca and Cayuga lake sections. It also has a very constant faunal combination.

[a] Sixteenth Ann. Rept. State Geol. New York, 1898, p. 319.

T. MODIELLA PYGMÆA ZONE.

Stratigraphy.—The shale in this zone is compact and fairly uniform throughout. It is not very fossiliferous, but by no means barren, except where thin layers of fine shale occur.

Faunule.—This is distinctly a pelecypod zone in which small pelecypods, such as *Nucula*, *Modiella*, *Palæoneilo*, and *Tellinopsis* are common. *Leiopteria* is frequently found near the center of the zone. The total number of species in the zone is large because of the occasional appearance of a number of rare species. The number of species of brachiopods are to those of pelecypods as 27 to 39. Of the brachiopods, *Spirifer pennatus* and *Ambocœlia umbonata* are found in all parts of the zone, sometimes being very common. *Stropheodonta*, *Nucleospira*, and *Reticularia* are absent. *Nucula*, *Nuculites*, *Modiella*, and *Palæoneilo*, which are rare in the lower zones, become common in this zone, though never abundant. The faunule disappears with the appearance of *Leiorhynchus laura* and *Orbiculoidea*.

Locality.—Shurger Glen, 40 feet below the Tully limestone. A Septaria layer is embedded in the upper few feet of this zone. The total thickness is 98 feet.

U. AMBOCŒLIA PRÆUMBONA ZONE.

Faunule.—This is a transition zone between T and V. It is characterized by the commonness of *A. præumbona*, which appeared a foot below this for the first time in this section, and in the reappearance of *Spirifer tullius*, which, until within a foot of this zone, was not present in the shale below for 20 feet. The faunal combination is not plain.

Locality.—Shurger Glen. Underlies the concretionary layer of Zone V. Five feet thick.

NOTE.—A bed in the Kashong (Seneca Lake) section contains the following species:

Ambocœlia præumbona.	Orbiculoidea lodiensis media.?
Leiorhynchus laura.	Chonetes mucronatus.

This faunule is probably a continuation of that at Cayuga Lake.

V. ORBICULOIDEA OR MODIFIED LEIORHYNCHUS ZONE.

Leiorhynchus laura and *Orbiculoidea lodiensis media* in abundance in a fine shale make this a very distinct zone. It may be considered a *Leiorhynchus* zone with *Orbiculoidea lodiensis media*, modified by the addition of *S. tullius* and *Ambocœlia præumbona*. In the center of the zone, however, the faunule is, with the addition of *O. lodiensis media*, an almost typical *Leiorhynchus* fauna. The *Leiorhynchus laura* and *Orbiculoidea lodiensis media* are very large and in an excellent state of

preservation in the concretionary layer, which is embedded in the fine shale of this zone. These concretions are over a foot in horizontal diameter.

Locality.—Shurger Glen, Salmon River, Lake Ridge, King Ferry, 30 feet below the Tully limestone.

W. (TRANSITION ZONE.)

Faunule.—The abundance of *Rhipidomella vanuxemi* and *Phacops rana*, which are rare in the next zone above, and the frequency with which *Pholidops hamiltoniæ* and *Dalmanites boothi* occur, present the appearance of a somewhat distinct faunule. However, *Chonetes mucronatus*, *Leiorhynchus laura*, *Spirifer audaculus*, *Stropheodonta junia*, and *S. perplana* are common to both.

The faunule can not be taken as a part of either Zone V or Zone X, although it contains a number of species of each, nor can it be considered a separate zone. During its deposition the conditions permitted the migration of a *Spirifer-Atrypa* faunule, together with *R. vanuxemi* and *P. rana*, and at the same time were not unfavorable to some of the species of the *Orbiculoidea* faunule.

Locality.—Shurger Glen. In a pyritiferous concretionary layer, 23 feet below the Tully, 10 feet thick.

X. SPIRIFER-ATRYPA ZONE.

Faunule.—*Atrypa reticularis*, *Athyris spiriferoides*, and *Spirifer audaculus* occur here in very great abundance. *S. granulosus* has a greater development than in any other portion of the section. *Leiorhynchus laura* is less abundant than in the zone below and is not found in the *Cystodictya* zone. Bryozoa, which were rare in Zone W, begin to be abundant and continue in great numbers to the Tully limestone.

Locality—Shurger Glen. Nine feet below the Tully limestone.

Y. CYSTODICTYA ZONE.

Stratigraphy.—The Hamilton stage closes with this zone, which includes an alternation of limestone and limy shales and a nodular layer. This condition is seen at Ludlowville, Lake Ridge, and King Ferry.

Faunule.—The zone is rich in Bryozoa, especially *Cystodictya incisurata*, and crinoid stems. *Tropidoleptus carinatus* is the fossil most often seen in the upper portion. *Spirifer pennatus* and *S. audaculus* are very common, while *S. marcyi* is represented by well-preserved specimens in the calcareous shales 5 feet below the Tully limestone. Pelecypods are very rare in the upper few feet. This, with a slight modification, is the same as the *Cystodictya* faunule of Grabau, which at Eighteenmile Creek occurs in the Lower Hamilton.

Locality.—Shurger Glen, Salmon Creek, Lake Ridge. In contact with the Tully limestone.

NOTE.—The Hamilton formation in the Kashong Creek section, Seneca Lake, closes with a fine shale 7 feet thick, very much like the Genesee in appearance and very poor in fossils.

The faunule of this zone is:

Ambocœlia umbonata.
Pholidops hamiltoniæ.
Phacops rana.
Tropidoleptus carinatus.
Ostrocods.
Palæoneilo constricta.
Tellinopsis subemarginata.

EXPLANATION OF DIAGRAMS, PL. V.

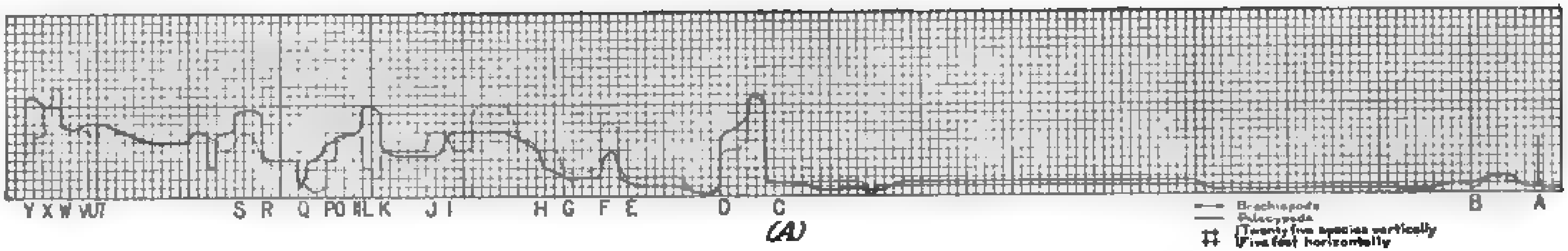
Diagram A.—With the exception of Zone A, 2 inches thick, 12 feet above the Onondaga (Corniferous) limestone, which is very rich in individuals, the number of species of Pelecypoda and Brachiopoda is very uniform throughout the soft shales until Zone D is reached. A few feet of the Upper Marcellus shales are quite fossiliferous, but the number of species is not large. The concretionary layer of Zone C contains a faunule fairly rich in individuals, but poor in species.

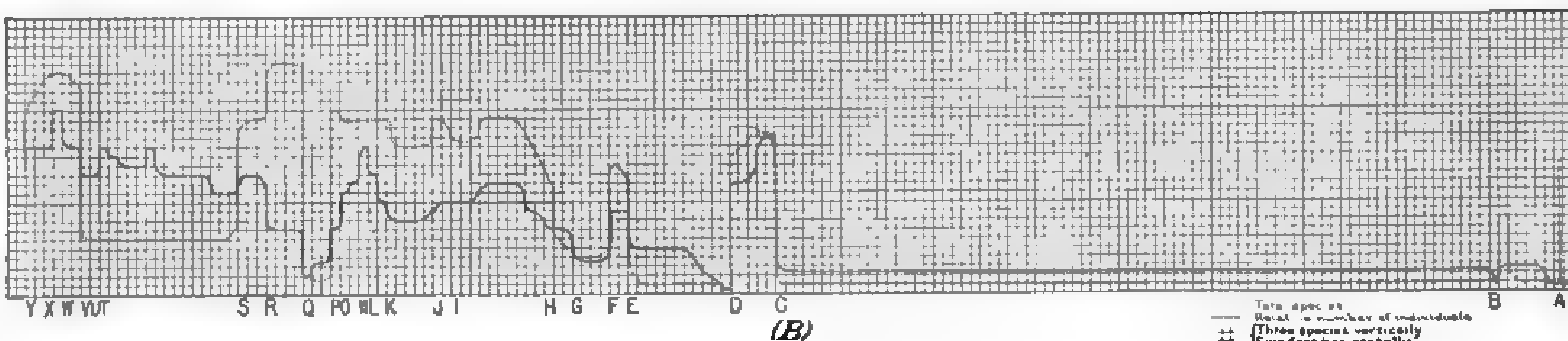
As indicated by the angle, Zone D is sharply defined from the shales above and below by the great abundance of species and individuals as well as by the greater hardness of the rock. With the exception of a portion of Zone X, the lower 10 feet of Zone D contains more species of both Brachiopoda and Pelecypoda than the same number of feet in any other part of the section. In the lower portion of the zone the brachiopods and pelecypods are represented by an equal number of species. In the upper portion both decrease in the number of their species, but the lamellibranchs suffer the greater loss.

The most barren shales of the section above Zone D, both in individuals and in species, are the 5 feet of fine black shales immediately in contact with it. The black shales of this zone (E) are very noticeable.

Zone F, which is a coralline zone, is rich in species, especially of pelecypods. After reaching a low point in Zone G there is a rapid increase in pelecypods, the increase in brachiopods remaining almost uniform throughout Zone I, while the pelecypods reach a high point in the center of the zone, but fall below the Brachiopoda toward the upper portion.

The next noticeable change is in the Encrinal bed, Zone L, where the pelecypods are extremely rare, while the brachiopods have a rich development. The brachiopods gradually decrease in the number of species until Zone Q is reached, where there is a greater paucity than in any other zone in the Upper Hamilton. The pelecypods become common in Zones O, M, and N, but become rare in species in Zone Q. In the 35 feet above Zone Q there is an increase, which culminates in Zone S, the brachiopods being predominant. Above Zone S to Zone





A. DIAGRAM SHOWING RELATIVE ABUNDANCE OF PELECYPODA AND BRACHIOPODA IN THE CAYUGA LAKE SECTION.
B. DIAGRAM SHOWING RELATIVE ABUNDANCE OF INDIVIDUALS AND SPECIES IN THE CAYUGA LAKE SECTION

X, with one local exception, the number, both of pelecypods and of brachiopods, is quite uniform. In Zone X the pelecypods reach their greatest development in the section, the brachiopods also being well toward their highest point.

The impure limestones of the upper few feet, with which the Hamilton formation closed, seemed unfavorable for pelecypods, as was the case in the Encrinal beds, and very favorable for brachiopods. From Zone X the pelecypods decrease and the brachiopods increase to the contact with the Tully limestone.

Diagram B.—The abundance of individuals is represented only approximately, as there is no practical method of determining accurately the actual number of individuals to each 5 feet.

In the fine shales of the Marcellus are thin layers full of *Styliola* and *Tentaculites* (these are not represented in the diagram). Above Zone A, which is very rich in individuals, the shale is almost barren as far up as it was exposed at this station (Union Springs), with the exception of *Tentaculites* and *Styliola*. For a few feet below the limestone with which the Marcellus closes there is an abundance of individuals of *Leiorhynchus limitare* and of *Orthoceratites*. The shales above this limestone, Zone C, are almost barren in many places, but now and then a fossil is found. Occasionally a thin layer of fine shale a fraction of an inch thick contains *Leiorhynchus laura* or *Strophalosia truncata* in great numbers.

In Zone D the impure limestone which forms the capping of Moonshine Falls seemed richer in individuals than the lower shales of this zone. This may, however, have been due to the more favorable collecting because of the weathering out of the fossils. Above Zone D are a few feet of almost completely barren shales, Zone E; above these shales the remaining 30 feet of Zone E continues poor in individuals and species to Zone F. In Zone F there is a sudden increase in the number of species and individuals, which makes it a quite distinct zone. The number of individuals, however, did not increase in the same ratio as the species. From Zone G to the middle of Zone I there is a rather gradual increase in species and individuals. From this point the number of species decrease to the Encrinal beds, while the number of individuals vary. The species become abundant in the upper part of the Encrinal bed and decrease to Zone Q, in which the shale is more barren, in species and individuals, than in any other zone in the Upper Hamilton.

The great abundance of individuals of the Zones P and R is shown. Zone R is, according to the diagram, the most fossiliferous zone (in individuals) in the section, although the number of species is by no means large.

From Zone S to Zone W there is a rather regular increase in the number of species, while the number of individuals is rather small. Zone S is rich in number of species as well as in abundance of indi-

viduals. Zone V, the *Orbiculoidea* zone, is separated from the other zones not only by its faunal combination, but in the fewness of its species; the number of individuals is not greatly different from that of the shale below. Zone X is the richest in species of any zone in the section. The abundance of individuals is great in proportion. Zone X was worked more thoroughly than any other except Zone Y—a fact which will in a measure account for the large numbers of species and individuals in the collection. From this zone to the Tully limestone the total number of species becomes less.

CHAPTER IV.

ANNOTATED LIST AND CLASSIFICATION OF SPECIES FOUND IN THE HAMILTON FORMATION OF THE CAYUGA LAKE SECTION.

Subkingdom COELENTERATA.

Class ANTHOZOA-ACTINOZOA.

The members of this class are, with a few exceptions, rare in the Cayuga Lake section. They are, however, of considerable importance since, when they are common, they are associated with a peculiar combination of species.

Subclass TETRACORALLA Haeckel.

Family ZAPHRENTIDÆ E. & H.

Genus STREPTELASMA Hall.

1. Streptelasma rectum Hall.

Ill. Dev. Fos. Hall, 1876, pl. 19.

This is the commonest of the corals at Cayuga Lake. It is chiefly confined to the upper 150 feet of the section. When it occurs with *Stropheodonta* it has a definite faunule.

Genus ZAPHRENTIS Rafinesque.

2. Zaphrentis simplex Hall.

Ill. Dev. Fos. Hall, 1876, pl. 21.

Four specimens of this species were found in the *Cystodictya* zone (Y).

Genus AMPLEXUS Sowerby.

3. Amplexus sp. undet.

Ill. Dev. Fos. Hall, 1876, pl. 3.

Next to *Streptelasma* in abundance is a species of *Amplexus*, found principally in the *Modiella* zone (T). It differs from the figures of *A. hamiltoniæ* and *A. intermedius*. The coral is very much flexed and has a jointed appearance, the constrictions sometimes being very marked.

Family CYATHOPHYLLIDÆ E. & H.

Genus HELIOPHYLLUM Hall.

4. Heliophyllum halli E. & H.

Ill. Dev. Fos. Hall, 1876, pl. 23.

This species is restricted to Zone D, with the exception of a single specimen from a doubtful locality in the Upper Hamilton. A number of specimens were obtained, two of the largest of which measured 220 and 270 mm. in length and 65 mm. in diameter. *H. halli* is very common in the "Basal limestone" of Ontario County, and is confined to a narrow zone within a few feet of the Encrinal beds in the Eighteenmile Creek section.

This species is very common in the "Basal limestone" of the Seneca Lake section.

5. Heliophyllum confluens Hall.

Ill. Dev. Fos. Hall, 1876, pl. 26.

A single specimen was found in this section—in the Encrinal beds of Paines Creek. At Eighteenmile Creek *H. confluens* is also restricted to the Encrinal beds.

Genus DIPHYPHYLLUM Lonsdale.

6. Diphyphyllum archiaci Billings.

Geol. Sur. Mich., vol. 3, 1873–1876, p. 126, pl. 47.

This species was found in Zone Y. A cross section showed the characteristic arrangement of the septa.

Subclass HEXACORALLA Haeckel.

Suborder TABULATA E. & H.

Family FAVOSITIDÆ E. & H.

Genus FAVOSITES Lamarck.

7. Favosites argus Hall.

Ill. Dev. Fos. Hall, 1876, pl. 13.

One specimen from Zone Y is probably of this species. It is of very much the shape of fig. 2, pl. 13, of the "Devonian Fossils." The arrangement of the large and small cells can not be made out.

8. Favosites sp. undet.

Favosite corals from several zones were too imperfectly preserved for specific identification. They did not show any of the specific characters of *F. argus*.

Genus MICHELINIA de Koninck.

9. Michelinia stylopora Eaton.

Ill. Dev. Fos. Hall, 1876, pl. 18.

This species is common in Zone F, but nowhere else in the section. At Eighteenmile Creek it is restricted to a few feet at the base of the Lower Hamilton. At Kashong Creek very large specimens of this species occur in a narrow bed 13 feet above the "upper fall" (above Encrinal). A few specimens were also found in the "Basal limestone" of Slate Rock Run.

Genus TRACHYPORA E. & H.

10. Trachypora (Dendropora) ornata Rominger.

Geol. Sur. Mich., vol. 3, 1873–1876. p. 62, pls. 23–24.

A few well-marked fragments of this species were found in the *Cystodictya* zone (Y), and in the Encrinal band. This species is not uncommon in the shales forming the falls below the Encrinal in the Kashong Creek section.

Family AULOPORIDÆ Nicholson.

Genus AULOPORA Goldfuss.

11. Aulopora serpens Goldfuss.

Geol. Sur. Mich., 1873–1876, p. 81, pl. 33.

Two very imperfect fragments of this species were found.

Genus CERATOPORA Grabau.

12. Ceratopora dichotoma Grabau.

Proc. Bos. Soc. Nat. His., vol. 23, 1899, p. 418, pl. 4.

This species, with well-marked characters, was found in Zones F and O. Excellent specimens also occur above the Encrinal at Kashong Creek.

Family SYRINGOPORIDÆ E. & H.

Genus SYRINGOPORA Goldfuss.

13. Syringopora sp. undet.

Geol. Sur. Mich., vol. 3, 1873–1876, p. 79.

A colony of this genus 10 or 12 feet long and 5 to 8 inches in thickness occurs in the lower part of Zone D. The specific characters are not distinct enough to warrant a specific identification. The "Basal limestone" of the Slate Rock Run (Seneca Lake) contains many colonies of this coral.

Family CHÆTETIDÆ E. & H.

Genus CHÆTETES Fischer.

14. Chætetes fructicosa Hall.

Ill. Dev. Fos. Hall, 1876, pl. 38.

A few specimens of this species were obtained from the upper portion of the Upper and Lower Hamilton.

Other species of *Chætetes* were found, but were too imperfect to permit of definite identification.

Subkingdom ECHINODERMATA.

Class CRINOIDEA Miller.

With the exception of three poorly preserved specimens, the crinoids are represented by crinoid joints and a very few plates. No other class of Echinodermata was found.

Genus GRANATOCRINUS Troost.

15. Granatocrinus (Pentremilis) leda Hall.

Fifteenth Rept. N. Y. State Mus. Nat. Hist., 1862, p. 149, pl. 1.

A complete but badly crushed specimen of this species was found in Zone O. Radial plates were obtained from Zones T and I.

Genus ANCYROCRINUS Hall.

16. Ancyrocrinus bulbosus Hall.

Fifteenth Rept. N. Y. State Mus. Nat. Hist., 1862, p. 90, pl. 1.

A specimen of this species was found in Zone L.

Genus DICHOCRINUS Münster.

17. Dichocrinus sp.?

A body without arms, from Zone I, was doubtfully referred to this genus.

18. Crinoid stems and plates.

The centers of abundance of crinoids, as is shown by the stems, joints, and plates, are, in this section, in Zones D, F, L, M, N, S, and Y. For a faunal study a record of these crinoid remains is as important as the record of any other fossil.

Bryozoa flourished when the conditions were favorable to the development of crinoids. The only exception is Zone F.

Subkingdom VERMES.

Suborder TUBICOLA.

Genus SPIRORBIS Daudin.

19. Spirorbis angulatus Hall.

Fifteenth Rept. N. Y. State Mus. Nat. Hist., p. 84.

A few casts of this tube were found on an *Orthoceras* in the upper Marcellus.

Subkingdom MOLLUSCOIDEA.

Class BRYOZOA Ehrenberg.

A number of genera and species of Bryozoa not included in the following list were found. The great amount of time necessary to make accurate identifications, together with the imperfect condition of these fossils, made a more complete list impossible. The centers of abundance of this class are Zones D, L, S, and Y.

Order GYMNOLÆMATA Allman.

Suborder CYCLOSTOMATA Busk.

Family DIASTOPORIDÆ Busk.

Genus HEDERELLA Hall.

20. Hederella canadensis Nicholson.

Pal. N. Y., vol. 6, 1887, p. 277; pl. 65.

A mass of this parasitic bryozoan was found in Zone Y.

Genus REPTARIA Rolle.

21. Reptaria stolonifera Rolle.

G. B. Simpson, Handbook N. A. Pal. Bry., p. 599, pl. 25.

This species was found in the Marcellus shale incrusting an *Orthoceras*, and in Zone Y incrusting a goniatite. It is rare in this region.

Suborder CRYPTOSTOMATA Vine.

Family CYSTODICTYONIDÆ Ulrich.

Genus TÆNIOPORA Nicholson.

22. Tæniopora exigua Nicholson.

Pal. N. Y., vol. 6, 1887, p. 263, pl 62.

A few specimens of this species were obtained from Zone Y. It is very rare here, and is so reported from Eighteenmile Creek.

Genus CYSTODICTYA Ulrich.

23. Cystodictya incisurata Hall.

Pal. N. Y., vol. 6, 1887, p. 241, pl. 40.

This is by far the most abundant bryozoan in the section. In Zone Y almost every piece of shale contains a fragment. It is common in the "*Stictopora* zone" of Grabau at Eighteenmile Creek.

Family FENESTELLIDÆ King.

Genus POLYPORA McCoy.

24. Polypora multiplex Hall.

Rept. State Geol. N. Y., 1886, p. 66, pl. 11.

A specimen of this species showing the cellular face was found in Zone S. A great many specimens showing the noncellular face may be of this genus and species, but can not be positively identified as such.

25. Bryozoa, undet.

The distribution of Bryozoa is given under crinoid stems.

Class BRACHIOPODA.

The classification of Brachiopoda, as given by Schuchert in Bulletin No. 87 of the United States Geological Survey, is used throughout this paper.

Adjustment to environment.—It was found in the study of the faunules of the Hamilton formation that the Brachiopoda were, as a rule, more closely adjusted to their environment than the Pelecypoda. This is shown in the greater definiteness of the faunule combinations of the Brachiopoda and in the often sudden disappearance of every abundant species, and even genera, with an apparently slight change of sedimentation, and their equally sudden reappearance upon the substitution of favorable conditions. The table of faunal zones at the end of the paper makes further comment unnecessary.

Order ATREMATA Beecher.

Superfamily LINGULACEA Waagen.

Family LINGULIDÆ Gray.

Genus LINGULA Bruguière.

26. Lingula delia Hall.

Pal. N. Y., vol. 4, 1867, p. 12, pl. 2.

Zone V (*Orbiculoidea* zone) contains excellent specimens of this species, fully 25 mm. in length and 16 mm. in width. It is rare in every part of the section, but is occasionally found between Zone D and Zone Y.

27. Lingula densa Hall.

Pal. N. Y., vol. 4, 1867, p. 11, pl. 2.

A specimen from Zone T was more closely related to this than to any other species described by Hall. It measured 12 mm. in length and 8 mm. in width.

28. Lingula ligea Hall.

Pal. N. Y., vol. 4, 1867, p. 7, pl. 1.

Three specimens from Zones I, X, and Y, 4 mm., 4 mm., 9 mm. in length and 2 mm., 2½ mm., and 5 mm. in width, respectively, were referred to this species.

Genus DIGNOMIA Hall.

29. Dignomia alveata Hall.

(*Lingula alveata*) Pal. N. Y., vol. 4, 1867, p. 12, pl. 2.

One plainly marked specimen of this species was found in the Encrinal. The same species is reported from the upper portion of the Upper Hamilton at Livonia.

Order TELOTREMATA Beecher.

Superfamily RHYNCHONELLACEA Schuchert.

Family RHYNCHONELLIDÆ Gray.

Genus CAMAROTŒCHIA Hall and Clarke.

30. Camarotœchia congregata Conrad.

(*Rhynchonella congregata*) Pal. N. Y., vol. 4, 1867, p. 341, pl. 54.

This species is very rare, being found in but four zones. The specimens are few and so poorly preserved that it is difficult to make a specific identification with certainty.

31. Camarotœchia dotis Hall.

(*Rhynchonella dotis*) Pal. N. Y., vol. 4, 1867, p. 344, pl. 54A.

In the crystalline limestone of the Encrinal bed, Zone L, a number of specimens possessing the characteristics of this species were found.

32. Camarotœchia horsfordi Hall.

(*Rhynchonella horsfordi*) Pal. N. Y., vol. 4, 1867, p. 339, pl. 54.

This species was found in the Encrinal bed and in Zone Y.

33. Camarotœchia prolifica Hall.

(*Rhynchonella prolifica*) Pal. N. Y., vol. 4, 1867, p. 343, pl. 54A.

Specimens from five zones were referred to this species. The specimens are so crushed that the identification in some cases is doubtful

34. Camarotœchia sappho Hall.

(*Rhynchonella sappho*) Pal. N. Y., vol. 4, 1867, p. 340, pl. 54.

The specimens of this species were well preserved. They were found in the Encrinal bed, Zone D, and in the *Cystodictya* zone (Y).

Genus HYPOTHYRIS King.

35. Hypothyris cuboides Sowerby.

Pal. N. Y., vol. 8, pt. 2, 1893, p. 200, pl. 60.
(*Rhynchonella venustula*) Pal. N. Y., vol. 4, 1867, p. 346, pl. 54A.

Nodules almost completely made up of this species were found embedded in the shale on the contact with the Tully limestone. This species was of considerable importance in correlating the Tully limestone with the Upper Devonian of Europe. The occurrence of this species in the Hamilton shales at Cayuga Lake shows that, in this region at least, the migration took place while the muds of the Hamilton formation were still soft, and that the conditions were very favorable for a rapid development.

Genus LEIORHYNCHUS Hall.

This genus appeared to be well adapted to conditions unfavorable to all but a few species. In this section it is always found in greatest abundance where other species are rare. The fine muds of the first, second, and third *Leiorhynchus* and the *Orbiculoidea* zones were especially favorable for its development. The change of species of this genus between the Marcellus (*L. limitare*) and the Hamilton (*L. laura*) did not materially affect the faunules.

36. Leiorhynchus laura Billings.

(*L. multicosta* Hall) Pal. N. Y., vol. 4, 1867, p. 358, pl. 56.

This species attains its greatest size and abundance in the *Orbiculoidea* zone (V). In this zone one specimen from a concretion measured 28 mm. in length and 27 mm. in width. Another concretionary layer in the second *Leiorhynchus* zone (C) afforded large, perfect specimens. It is found throughout the section in thin layers of fine shale. These layers, which are a fraction of an inch thick, are occasionally almost entirely made up of flattened specimens. This is especially true of the first, second, and third *Leiorhynchus* zones. This species appears immediately above the limestone capping the Marcellus shale. Although *L. limitare* is very abundant below this limestone, it does not appear above it. Several doubtful specimens found in Zone E had somewhat the appearance of *L. dubium* Hall.

37. **Leiorhynchus limitare** Vanuxem.

(*L. limitaris*) Pal. N. Y., vol. 4, 1867, p. 356, pl. 56.

In the Cayuga Lake section this species is confined to the Marcellus shale. It is preserved in an almost perfect condition in the concretions underlying the falls in Great Gully Creek, near Farleys post-office.

Superfamily TEREBRATULACEA Waagen.

Family CENTRONELLIDÆ Hall and Clarke.

Genus CENTRONELLA Billings.

38. **Centronella impressa** Hall.

Pal. N. Y., vol. 4, 1867, p. 402, pl. 61A.

A considerable number of specimens of this species preserved the exterior and interior of the dorsal and the exterior of the ventral valve. The average size is about 14 mm. in length and 11 mm. in width. This rare but strongly marked species is restricted to the Encrinal bed (Zone L) at Cayuga Lake, and is found only in the Encrinal at Eighteenmile Creek.

Family TEREBRATULIDÆ Gray.

Subfamily MEGALANTERINÆ Waagen.

Genus CRYPTONELLA Hall.

39. **Cryptonella planirostris** Hall.

Pal. N. Y., vol. 4, 1867, p. 395, pl. 61.

A single individual of this species was found in the upper portion of Zone D. At Eighteenmile Creek it is found commonly in the Encrinal and rarely in two zones in the Lower Hamilton.

40. **Cryptonella rectirostris** Hall.

Pal. N. Y., vol. 4, 1867, p. 394, pl. 61.

The specimens of this species are all somewhat flattened and bear a resemblance to *Eunella lincklæni*. They are, however, more angular and the beak is not so much incurved as in *E. lincklæni*. They are restricted to Zone D. At Eighteenmile Creek this species is found in a calcareous bed near the base of the Lower Hamilton, but nowhere else in that section.

Subfamily TEREBRATULINÆ Dall.

Genus EUNELLA Hall and Clarke.

41. Eunella lincklæni Hall.

(*Cryptonella lincklæni*) Pal. N. Y., vol. 4, 1867, p. 397, pl. 60; vol. 8, pt. 2, p. 290.

This species is restricted to Zones D, L, and the upper portions of X and Y. The specimens are often exfoliated, but are not crushed and can readily be identified. It is not reported from Livonia or Eighteen-mile Creek.

Family TEREBRATELLIDÆ King.

Subfamily TROPIDOLEPTIINÆ Schuchert.

Genus TROPIDOLEPTUS Hall.

42. Tropidoleptus carinatus Conrad.

Pal. N. Y., vol. 4, 1867, p. 407, pl. 62.

The characteristic fossil ranges from the Hamilton-Onondaga zone (A) to the contact of the Tully and Hamilton. In the Cayuga Lake section it seemed to thrive best in the calcareous sediments. Specimens from Zones Y, P, and K measured 25 mm. in length and 30 mm. in width, the average size being 20 by 25 mm.

The occurrence of *T. carinatus* in Zone A shows that the migration of this species must have taken place as early as, and probably during, the oscillation which closed Onondaga and began Marcellus time. The changes in level which ushered in the Marcellus must have been widespread, and it is probable that, at this time, the connection between North America and South America was such that a migration of species was permitted. Rathbun's sandstone of Maecurú and Curuá, which contains *Anoplotheca flabellites*, *Vitulina pustulosa* and *Tropidoleptus carinatus*, was correlated with the Marcellus and Onondaga because of the mixture of Onondaga and Hamilton species. Thus far *V. pustulosa* has not been found lower than Zone D, but, accepting Rathbun's correlation, it should be, and may yet, be found as low as *T. carinatus*, if the migration took place at this time.

The only variations noted are between the smaller specimens from the less calcareous shales, which are sometimes almost mucronate, and the large forms of the calcareous shales which are rounded on the cardinal angle. The fact that the young are always less rounded than the older ones indicates that in the finer shales the individuals did not reach maturity.

In eastern New York where the sediments remain of very much the same character throughout the Hamilton and Ithaca groups, *T. cari-*

natus extends into the Chemung. In western New York it disappears with the close of the Hamilton. This species, unlike its associate in South America, *V. pustulosa*, is found in Europe. In North America it has not been reported farther south than Jackson County, Ill.

Superfamily SPIRIFERACEA Waagen.

Family ATRYPIDÆ Gill.

Subfamily ATRYPINÆ Waagen.

Genus ATRYPA Dalman.

43. Atrypa reticularis Linnæus.

Pal. N. Y., vol. 4, 1867, p. 316, pl. 51–53A.

This fossil is not by any means a common one in this section. It is abundant in the upper 25 feet below the Tully limestone and common in the *Stropheodonta*-coralline zone (S). Elsewhere it is seldom seen. The specimens are of the usual form and surface markings.

Family SPIRIFERIDÆ King.

Subfamily SUESSIINÆ Waagen.

Genus CYRTINA Davidson.

44. Cyrtina hamiltonensis Hall.

Pal. N. Y., vol. 4, 1867, p. 268, pls. 27 and 44.

This is a rare species throughout the section. It is occasionally found in Zone D, but elsewhere it is rare. At Eighteenmile Creek it is common in a few feet of shale near the top of the Lower Hamilton.

Subfamily TRIGONOTRETINÆ Schuchert.

Genus SPIRIFER Sowerby.

45. Spirifer audaculus Conrad.

(*S. medialis*) Pal. N. Y., vol. 4, 1867, p. 227, pl. 38.

The vertical distribution of this species is almost as uniform as that of *S. pennatus*. Hall says that it is an abundant species, coming next to *S. pennatus* in the number of individuals. The greatest abundance of the species, in the Cayuga Lake section, is 20 or 25 feet below the Tully. It is wanting in the second *Leiorhynchus* zone and very rare in the lower half of the Lower Hamilton. The form is very variable. It is impossible to tell in poorly preserved individuals whether the specimens are *S. audaculus* or *S. audaculus macronotus*. At Eighteenmile Creek it has four zones of abundance, two near

the base of the Hamilton, one a foot below and one a foot above the Encrinal. In the intervening space between the zones of abundance the species is either very rare or wanting.

46. Spirifer audaculus macronotus Hall.

Pal. N. Y., vol. 4, 1867, p. 231, pl. 38*a*.

This variety of *S. audaculus* is, in its extreme form, readily distinguished from *S. audaculus*, but the intermediate forms are difficult to determine. In this identification all doubtful forms were called *S. audaculus*.

47. Spirifer divaricatus Hall.

Pal. N. Y., vol. 4, 1867, p. 213, pl. 32.

This species was found only in the Encrinal bed (Zone L) and in Zone D. In the former it was not uncommon, but in the latter only one fragment was obtained. The markings of this fossil are so characteristic that there can be no doubt as to the identification. The bifurcating plications and fine imbricating, lamellose striæ are seen in all the specimens. It is reported from the 17 feet of soft shales immediately overlying the Encrinal at Livonia, but has not been noted as occurring at Eighteenmile Creek.

S. divaricatus is an Onondaga species which was able to survive the conditions of the Hamilton. Hall and Clarke say that it is the only representative of this type of structure (arrangement of the plications) in the Hamilton faunas, but from the Upper Devonian onward the species multiply rapidly, becoming most abundant and varied in the different faunas of the Lower Carboniferous and continuing until the close of Paleozoic time.

48. Spirifer granulosus Conrad.

(*S. granulifera* Hall) Pal. N. Y., vol. 4, 1867, p. 223, pl. 36; vol. 8, pt. 2, p. 39.

In this section the range of this species is from the first *Terebratula* zone (D) to the Tully limestone, a distance of over 400 feet. It is found commonly in but three zones, I, L, and X. At Eighteenmile Creek it is wanting in the shales above the Encrinal beds. In this section it is especially common above and including the Encrinal. This is one of a number of species which show how little one can depend on a single species in correlating the smaller divisions of a formation like the Hamilton. Species which are restricted to the Lower Hamilton at Eighteenmile Creek or Livonia are sometimes restricted to the Upper Hamilton in this section or are found throughout the section, or vice versa.

The characters of the species are quite uniform. The variety described by Hall as *S. clintoni*, but not recognized by Schuchert, was found in Zone T. The measurements are: 75 by 55 mm. for the largest and 35 by 20 mm. for the smallest specimens.

49. Spirifer marcyi Hall.

Pal. N. Y., vol. 4, 1867, p. 226, pl. 37.

This spirifer is confined to the upper 15 feet of this section and is most common within 5 feet of the Tully. It is not reported as occurring below the Encrinal in any part of the State. The largest specimen measured 90 mm. in width and 30 mm. in length. No other spirifer found in this section is so well preserved and so striking. This fossil has not been found at Eighteenmile Creek. Clarke reports it in the upper 160 of the Hamilton of the Livonia salt shaft section. It is found in the upper 50 feet of the Upper Hamilton in the Kashong (Seneca Lake) section.

50. Spirifer pennatus Atwater.

(*S. mucronata*) Pal. N. Y., vol. 4, 1867, p. 216, pl. 34.

No other species is found so commonly from Zone D to the Tully limestone as is this one. It is wanting only in the fine shales of Zone Q, the 1½ feet of crystalline Encrinal beds, and in Zone E. In the Eighteenmile Creek section it is common below the Encrinal but extremely rare above.

S. pennatus, at Cayuga Lake, is variable in three particulars: (1) Gibbosity; (2) surface markings; (3) in the length of the mucronations. These variations are not progressive. A specimen which is gibbous is usually shorter and has fewer but stronger imbrications than the mucronate and flat kinds. There is no difficulty at any time in distinguishing the extremes of this species as developed at Cayuga Lake from *Delthyris consobrina* on the one hand and *Spirifer audaculus* on the other.

51. Spirifer tullius Hall.

(*S. tullia*) Pal. N. Y., vol. 4, 1867, p. 218, pl. 35.

Spirifer tullius is not abundant in any part of the section nor has it a great vertical range. With the exception of five or six specimens, which were found immediately below the Encrinal beds, the species is confined to the Upper Hamilton.

The characteristic fine striations are usually distinct except in the Encrinal, where the shell has been exfoliated in working it out of the limestone. One of the largest specimens from Zone I measured 16 mm. in width and 14 mm. in length. One specimen from Zone I measured 17 mm. in width and 13 or 14 mm. in length.

52. Spirifer macrus Hall.

(*S. macra*) Pal. N. Y., vol. 4, 1867, p. 190, pl. 27.

This species was found only in Zone A, 12 feet above the Onondaga (Corniferous) limestone. It is associated with Onondaga and Hamilton fossils. (*See Zone A.*)

Genus DELTHYRIS Dalman.

53. Delthyris consobrina d'Orbigny.

(*Spirifera ziczac*) Pal. N. Y., vol. 4, 1867, p. 222, pl. 35.

Spirifer pennatus occasionally approaches this species in its form and surface markings, the imbricating lamellæ being sometimes strongly arched and finer than normal. The number of plications of *D. consobrina* is, however, always less. In this section there is no difficulty in distinguishing between the extreme forms of the two species. This fossil is fairly common in Zones R and S, but is rare elsewhere in the section. At Eighteenmile Creek it is found only above the Encrinal, where it is restricted to two zones. It is not reported from Livonia.

54. Delthyris sculptilis Hall.

(*Spirifera sculptilis*) Pal. N. Y., vol. 4, 1867, p. 221, pl. 35.

This species is not uncommon in a weathered layer of the upper part of Zone D. It was not found elsewhere in the section. At Eighteenmile Creek it occurs only in the Encrinal. At Livonia it is found in two zones above the Encrinal.

Genus MARTINIA McCoy.

55. Martinia subumbona Hall.

(*Spirifera subumbona*) Pal. N. Y., vol. 4, 1867, p. 234, pl. 33.

A very few specimens of this species were found in Zone T. The surface markings could not be made out, but the general form was in accord with the descriptions. One specimen measured 15 mm. in length and 15 mm. in width.

Genus AMBOCŒLIA Hall.

56. Ambocœlia præumbona Hall.

Pal. N. Y., vol. 4, 1867, p. 262, pl. 44.

This species has a very limited vertical range in this section. It is found in Zone U as a center and a foot or two above and below. The specimens are rather smaller than the type specimens, but are quite characteristic. At Livonia it is restricted to the Upper Hamilton, and is common in but one zone, 48 feet thick, the lowest part of which is 17 feet above the Encrinal. It is rarely found above this. At Eighteenmile Creek it is restricted to the 3½ feet at the top of the Upper Hamilton. It might be inferred from its occurrence in these three sections that it is a characteristic Upper Hamilton fossil. In the Kashong (Seneca Lake) section it is restricted to the upper portion of the Upper Hamilton. The fact that it has not been found east of Cayuga Lake or west of New York State indicates that it originated in this region.

57. Ambocœlia umbonata Conrad.

Pal. N. Y., vol. 4, 1867, p. 259, pl. 44.

The gregarious character of this species is well shown in a description in one of the old New York reports.[a] In speaking of the shale at Eighteenmile Creek, Hall says: "The lower part of this shale resting on the Encrinal beds is completely filled with a small *Orthis* or *Stenecesma* (*Ambocœlia umbonata*). This species so abounds that in some places there is scarcely enough shaly matter to cause the mass to cohere." In the second *Ambocoelia* zone (R), described elsewhere, *A. umbonata* has a remarkable development. Elsewhere in the section layers an inch or less in thickness were found which were almost completely made up of them. In actual numbers there are a great many more *A. umbonata* than any other fossil. It extends from Zone A to Zone Y. Its vertical range is equally great at Livonia and at Eighteenmile Creek. The absence of *Tropidoleptus carinatus* wherever *A. umbonata* flourishes, and vice versa, is noticeable both here and at Eighteenmile Creek. *Phacops rana* is an associated fossil.

The variations of this species are principally confined to surface markings, although variation in size is common.

Dr. J. M. Clarke describes *A. spinosa* from the Livonia section:[b] "Surface bearing faint traces of concentric lines and covered with numerous elongate depressions which were probably the bases of insertion of epidermal spines." A number of individuals answering this description fairly well were found in Zone U, but were included with *A. umbonata*. Specimens covered with elongated pits resembling *A. umbonata* var. *nana*,[c] described by Grabau, have also been included with *A. umbonata*.

Genus RETICULARIA McCoy.

58. Reticularia fimbriata Conrad.

(*Spirifer fimbriata*) Pal. N. Y., vol. 4, 1867, p. 214, pl. 33.

In this section *R. fimbriata* extends from Zone D to Zone Y, but is never abundant. Aside from Zones D, N, and Y it is very rare. At Livonia it is not reported lower than the Encrinal, while at Eighteenmile Creek it does not occur above the Encrinal.

Family ATHYRIDÆ Phillips.

Subfamily HINDELLINÆ Schuchert.

Genus NUCLEOSPIRA Hall.

59. Nucleospira concinna Hall.

Pal. N. Y., vol. 4, 1867, p. 279, pl. 45.

This is a rare species in all parts of the section, and although it occurs in the highest zone (Y) and in Zone D, it was found in but two

[a] Fifth Annual Report, Geol. Sur. N. Y., 1841, p. 164.
[b] Report N. Y. State Geol., vol. 1, 1883, p. 177, pl. 4.
[c] Sixteenth Ann. Report State Geol. N. Y., 1898, p. 277.

other zones—S and L. The specimens have either the surface markings preserved or the muscular scars distinct.

At Livonia it is reported as occurring only in a concretionary layer 50 feet above the Encrinal. At Eighteenmile Creek it is very common in the upper foot of the Lower Hamilton.

Genus ANOPLOTHECA Sandberger.

60. Anoplotheca camilla Hall.

(*Cœleospira camilla*) Pal. N. Y., vol. 4, 1867, p. 329, pl. 52.

This species was found at the base of the Marcellus, in Zone A, associated with Hamilton and Onondaga (Corniferous) species. Two individuals measured 6 mm. and 5½ mm. in length and 6 mm. and 5½ mm. in width, respectively.

A layer of limestone 9 feet above the Onondaga limestone, in the Livonia salt section, contained this same species associated with an even more characteristic Hamilton fauna, but it does not appear in the typical Hamilton faunules.

Genus VITULINA Hall.

61. Vitulina pustulosa Hall.

Pal. N. Y., vol. 4, 1867, p. 410, pl. 62.

In the Cayuga Lake section *Vitulina pustulosa* is restricted to the Encrinal beds and Zone D, two rather thin zones over 150 feet apart, and to the Encrinal bed at Eighteenmile Creek. Prof. C. S. Prosser reports it as occurring in Schoharie County in the uppermost portion of the Hamilton,[a] and in what is apparently the Lower Hamilton, at Marshall Falls post-office in eastern Pennsylvania.[b]

In South America this species occurs throughout, not only what is correlated with the Hamilton, but the entire Devonian. In Bolivia it is reported by Steinmann from the "Conularia Schichten," which he correlated with the Onondaga and Marcellus, and in the Huamampampa sandstone, which is correlated with and includes the Hamilton, the Upper Devonian, and perhaps the Lower Carboniferous. In Brazil it is found in the sandstone of Maecurú and Curuá (Onondaga and Marcellus) and in the Erere sandstone (Hamilton) of Rathbun. In middle Argentina, Kayser found it in the "Kalkig sandig Banke" of "O. von Jachalthal" (Onondaga and Marcellus). In South Africa it was collected by Schenk in the Bokkenveld Mountains. At the present writing it has not been reported from Europe.

Two specimens from Zone D, at Cayuga Lake, measured 10 and 8 mm. in width, 8 and 6 mm. in length, and 4 and 3 mm. in thickness. Two specimens from the Encrinal measured 11 by 7 mm. and 11 by 10 mm.

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[a] Prosser, N. Y. Geol. Sur., 1895.

[b] Bull. 120, U. S. G. S., p. 21.

In the Cayuga Lake section this species in confined to two calcareous layers, Zones D and L. At Kashong Creek it occurs in the fine shales underlying the Tully and in the fine black shales overlying the "Basal limestone."

Subfamily ATHYRINÆ Waagen.

Genus ATHYRIS McCoy.

62. Athyris spiriferoides Eaton.

Pal. N. Y., vol. 4, 1867, p. 285, pl. 46.

This fossil is very common from the lower part of Zone I, 80 feet below the Encrinal bed, to the top of Zone X. Below this zone it was found in Zone A and in Zone D; elsewhere it is very rare.

Subfamily MERISTELLINÆ Waagen.

Genus MERISTELLA Hall.

63. Meristella haskinsi Hall.

Pal. N. Y., vol. 4, 1867, p. 306, pl. 49.

Specimens 22 mm. long and 20 mm. wide were found in the Encrinal bed and in Zone D. A portion of the shell was preserved, showing the wrinkled concentric lines which are crowded in front. On the exfoliated surface the faint radiating lines can be seen. This species has not been reported east of Seneca Lake nor west of Thedford, Canada. It was found only in the Encrinal at Eighteenmile Creek. It occurs in the "Basal limestone" of Slate Rock River (Seneca Lake section).

Order NEOTREMATA Beecher.

Superfamily DISCINACEA Waagen.

Family DISCINIDÆ Gray.

Genus ORBICULOIDEA d'Orbigny.

64. Orbiculoidea doria Hall.

(*Discina doria*) Pal. N. Y., vol. 4, 1867, p. 19, pl. 2.

Several specimens were referred to this species with some doubt. The specimens at hand have a more elevated apex and are smaller than is usual in *O. media*. This species is restricted to one zone at Eighteenmile Creek.

65. Orbiculoidea humilis Hall.

(*Discina humilis*) Pal. N. Y., vol. 4, 1867, p. 16, pl. 2.

A fragment of a large *Orbiculoidea* from Zone J was referred to this species.

66. Orbiculoidea lodiensis Vanuxem.

(*Discina lodensis*) Pal. N. Y., vol. 4, 1867, p. 22, pl. 2.

This species so closely resembles *O. media* that it is difficult to distinguish between them. The faint radiating lines are seen in specimens from Zone T. It is a rare species at Eighteenmile Creek, and is found in but two zones.

67. Orbiculoidea lodiensis media Hall.

(*Discina lodensis*) Pal. N. Y., vol. 4, 1867, p. 20, pl. 2.

This is a very common species in the *Orbiculoidea* zone (V). The concretionary layer, in which they are very large, abundant, and well preserved, was traced for a distance of 10 miles. Above and below this zone this fossil is found occasionally, but in no other zone in such abundance.

The *Orbiculoidea media* bed of Grabau, 5 feet above the Encrinal, is the only layer in which it is reported as common at Eighteenmile Creek.

Superfamily CRANIACEA Waagen.

Family CRANIIDÆ King.

Genus CRANIELLA Oehlert.

68. Craniella hamiltoniæ Hall.

Pal. N. Y., vol. 4, 1867, p. 27, pl. 3.

This is not an uncommon species in the upper part of Zone Y. Elsewhere in the section it is rarely found. It is a rare fossil at Eighteenmile Creek and Livonia.

Genus PHOLIDOPS Hall.

69. Pholidops hamiltoniæ Hall.

Pal. N. Y., vol. 4, 1867, p. 32, pl. 3.

This is a common fossil between Zones X and I, with the exception of the limestone of the Encrinal band. Below Zone I it was not found. The extremes in size are 3 mm. in length and 2 mm. in width for the smallest, and 4 mm. in length and 3 mm. in width for the largest, specimens. The vertical range at Eighteenmile Creek and Livonia is about the same as at the Cayuga Lake section, the center of abundance in those sections being in the upper part of the Lower Hamilton.

70. Pholidops oblata Hall.

(*P. oblata* and *linguloides*) Pal. N. Y., vol. 4, 1867, p. 414, pl. 3.

The only specimen of this species, found in Zone L, showed the interior of the ventral (?) valve, but the muscular scars were oblit-

erated. Following Schuchert, *P. linguloides* and *P. oblata* will be considered as the same species. At Eighteenmile Creek it was found in the Encrinal and in a zone 1 foot below. It was not reported from Livonia. Size 4½ mm. wide and 5½ mm. long.

Order PROTREMATA Beecher.

Superfamily STROPHOMENACEA Schuchert.

Family RAFINESQUININÆ Schuchert.

Genus STROPHEODONTA Hall.

71. Stropheodonta concava Hall.

Pal. N. Y., vol. 4, 1867, p. 96, pl. 16.

This species is restricted to three narrow zones, X and Y, and S, in the Upper Hamilton. The specimens are well preserved and show the characteristic form and surface markings. Both full-grown and young individuals were collected. The immature specimens do not possess the concavity of the mature individuals, but approach *S. demissa* in form. In both zones where *S. concava* is found, *Streptelasma rectum* is common.

At Eighteenmile Creek this species is rarely found below, and not above, a zone 6 inches thick a foot below the Encrinal. At Livonia it is common in three zones above, and including, the Encrinal, and rarely in two other zones. It is not reported from the Lower Hamilton.

Size 60 mm. in width and 55 mm. in length for the mature, and 40 mm. in width and 30 mm. in length for the immature, forms.

72. Stropheodonta demissa Conrad.

Pal. N. Y., vol. 4, 1867, p. 101, pl. 17.

The only specimen of this species was found in Zone I. At Eighteenmile Creek, with few exceptions, it is restricted to 6 inches of shale in the Lower Hamilton within a foot of the Encrinal bed. It is reported as occurring only in the Encrinal at Livonia.

Size 30 mm. in width and 20 mm. in length.

73. Stropheodonta inæquistriata Conrad.

Pal. N. Y., vol. 4, 1867, p. 106, pl. 18.

This species is found in the upper 25 feet of the Hamilton, in Zone S, in the Encrinal bed, in Zone I, and, rarely, in Zone D. Between these zones it is rare. Little variation, except in size, is noticeable in the specimens from the different zones.

The width along the cardinal lines of the largest specimen was 40 mm. and the length 28 mm. A smaller specimen measured 13 mm. in width and 10 mm. in length.

At Eighteenmile Creek and Livonia it is common, but has very much the same vertical distribution.

74. Stropheodonta junia Hall.

(*Stropheodonta textilis*) Pal. N. Y., vol. 4, 1867, p. 108, pl. 18.

This species is confined to the upper 35 feet of the Upper Hamilton, with the exception of a few specimens in Zone N. The specimens are large and well preserved. It is especially abundant at Lake Ridge in the calcareous shales immediately under the Tully limestone.

At Eighteenmile Creek it is rarely found, in a single zone, a foot below the Encrinal. It is reported as occurring quite commonly in the upper 200 feet of the Upper Hamilton at Livonia, but is not reported from the Lower Hamilton.

75. Stropheodonta perplana Conrad.

Pal. N. Y., vol. 4, 1867, p. 98, pls. 11, 12, 17, and 19.

This species is more abundant in this section than *S. inæquistriata* with which it is usually associated. The largest individuals occur in the limestone concretions of the Upper Hamilton. At Eighteenmile Creek it is a common fossil, but is not as abundant as *S. demissa*, a species which is seldom seen in the Cayuga Lake section. *S. perplana* is found throughout the Hamilton of the Livonia section.

76. Stropheodonta perplana var.

A single specimen with long, mucronate points, but with the characters of the coarser varieties of *S. perplana*, will not be given a varietal name until more individuals are found. It is possible that the mucronations were due to some disease of the animal. The length of the shell along the hinge line is 42 mm., the width of the body 18 mm., and the length of the shell 14 mm.

Genus PHOLIDOSTROPHIA Hall and Clarke.

77. Pholidostrophia iowaensis Owen.

(*Stropheodonta nacrea* Hall) Pal. N. Y., vol. 4, 1867, p, 104, pl. 18.

With the exception of the lower part of Zone I, where it is common, this species is very rare in the Cayuga Lake section. It is found rarely in Zones N and Y.

At Eighteenmile Creek it is found in both the Upper and Lower Hamilton. At Livonia it is reported from the Encrinal and from two zones 65 and 90 feet above. At Kashong Creek it occurs both above and below the Encrinal beds, but never in abundance.

Subfamily ORTHOTHETINÆ Waagen.

Genus ORTHOTHETES Fischer de Waldheim.

78. Orthothetes chemungensis var. arctistriatus Hall.

(*Streptorhynchus chemungensis arctostriata*) Pal. N. Y., vol. 4, 1867, p. 71, pl. 9.

This variety, though seldom common, is found in almost every zone in the Upper Hamilton, and is not uncommon, with the exception of

Zone E, in the Lower Hamilton above Zone D. It is quite constant in its form and surface markings. At Eighteenmile Creek it is scattered throughout the section from the lowest to the highest zone. It is rare above the Encrinal, but common in several zones below. At Livonia it is commoner above than below the Encrinal beds.

79. Orthothetes chemungensis var. perversus Hall.

(*Streptorhynchus chemungensis perversus*) Pal. N. Y., vol. 4. 1867, p. 72. pl. 9.

This fossil was not found above and rarely below the Encrinal beds at Cayuga Lake. This variety is readily distinguished from *O. chemungensis arctistriatus* by its larger form and surface markings. It is rare at Eighteenmile Creek, where it is found only below the Encrinal.

80. Orthothetes chemungensis var.

A variety of *Orthothetes* approaching Hall's type, *Streptorhynchus pectinacea*, was found in Zone A. All of the specimens are casts, or show only the interior of the shell. One very good specimen measures about 10 mm. in length, 15 mm. in width, and the cardinal area 2 mm. high. In this specimen there are seventeen prominent striæ, with from two to no weak striæ between. The surface is marked by very fine undulating concentric lines.

Family PRODUCTIDÆ Gray.

Subfamily CHONETINÆ Waagen.

Genus CHONETES Fischer de Waldheim.

81. Chonetes coronatus Conrad.

Pal. N. Y., vol. 4, 1867, p. 133. pl. 21.

A single specimen of dorsal valve of this species was found in Zone A, associated with Onondaga (Corniferous) species. With the exception of this zone and Zone D, it was not found below Zone H. Between Zone H and T it has its greatest abundance. In the upper 10 feet of the Upper Hamilton it is extremely rare.

At Livonia it is reported from the Encrinal and above, but was not found in the Lower Hamilton. With the exception of the Encrinal and a foot of shale immediately below, this species is rare at Eighteenmile Creek.

82. Chonetes lepidus Hall.

Pal. N. Y., vol. 4, 1867, p. 132. pl. 21.

This species is sometimes not easily distinguished from the young individuals of other species of *Chonetes*. Specimens from Zones X and Y possess a number of points of differences from the typical *C. lepidus*, but may be of this species. On page 133 of vol. 4, Pal. N. Y., Hall says that the original specimens designated as *C. lepida*

are very small, almost hemispheric shells. The striæ are very strong, angular, etc. This description accords fairly well with the specimens in question.

At Eighteenmile Creek *C. lepidus* is the most common species of *Chonetes* in the Hamilton shale. "It is everywhere abundant, in some layers extremely so."[a] This species is not so common at Cayuga Lake as either *C. scitulus*, *C. mucronatus*, or *C. vicinus*. It is found in all the zones of the Upper Hamilton with the exception of the Encrinal bed. In the Lower Hamilton it is not common in any zone and is entirely wanting in the lower half of Zone C.

83. Chonetes lineatus Conrad.

Pal. N. Y., vol. 4, 1867, p. 121, pl. 20.

This Onondaga (Corniferous) species was found in Zone A, where it is very common. It was associated with *Anoplotheca camilla*, *S. macrus*, *Chonetes coronatus*, *C. mucronatus*, and *Ambocœlia umbonata*.

84. Chonetes mucronatus Hall.

Pal. N. Y., vol. 4, 1867, p. 124, pls. 20 and 21.

This species is very common in the lowest zone in the section, Zone A. It is met with rarely in Zone C, and is common in the first *Terebratula* zone. Above this to the Encrinal its place is taken by *Chonetes vicinus*. In the Upper Hamilton it is a very common and well-preserved fossil. *C. mucronatus* is not common at Eighteenmile Creek, "where it is nearly restricted to the lower Moscow shales." At Livonia it is not reported from the Upper Hamilton, but is found in the Lower Hamilton.

85. Chonetes scitulus Hall.

Pal. N. Y., vol. 4, 1867, p. 130. pl. 21.

This species comes next to *C. mucronatus* in abundance in this section. It is rarely found in the first and second *Leiorhynchus* zones, but is common especially in the lower half of the Upper Hamilton.

At Livonia it is common throughout the Upper and Lower Hamilton, while at Eighteenmile Creek it is common in the Lower but rare in the Upper Hamilton.

86. Chonetes setigerus Hall.

Pal. N. Y., vol. 4. 1867, p. 130, pl. 21.

A single specimen of this species was found in Zone T.

87. Chonetes vicinus Castelnau.

(*C. deflecta*, Hall), Pal. N. Y., vol. 4, 1867, p. 128, pl. 21.

King Ferry station is one of the type localities for this species. As developed here it is distinguished from *C. mucronatus* by its larger

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[a] Tenth Annual Rept. State Geol. N. Y., 1898.

size and greater number and fineness of the striæ. The average size is 7 mm. in length and 13 mm. in width. It is an exceptionally abundant species in the first 115 feet below the Encrinal It was not found above or below this zone.

At Eighteenmile Creek it is common in one zone 2 or 3 feet above the Encrinal, but is rare in the Lower Hamilton. At Livonia it is found throughout the section, with the exception of the upper 160 feet of the Upper Hamilton.

87a. Chonetes sp.

A specimen which could not be referred to any described species of *Chonetes* was found in Zone I. The size is 4 mm. in length and 7 mm. in width. The striæ are fine and round and number 32. The spaces between the striæ have a reticulate appearance.

Subfamily PRODUCTINÆ Waagen.

Genus PRODUCTELLA Hall.

88. Productella spinulicosta Hall.

Pal. N. Y., vol. 4, 1867, p. 160, pl. 23.

This is a widespread but not an abundant species in this section, being found in almost every zone from Zone D to the Tully limestone. It was found in the arenaceous shales of the Marcellus, but is wanting in the fine shales of Zone C, its place being taken by *Strophalosia truncata*. A specimen from Zone Y bears a strong resemblance to *P. lachrymosa* (Conrad) of the Chemung and may be of that species. *P. spinulicosta* is an extremely variable species.

89. Productella navicella Hall.

Pal. N. Y., vol. 4, 1867, p. 156, pl. 23.

A few specimens from concretionary layers in the upper part of Zone C, about 65 feet below Zone D, in Dean Creek, were referred provisionally to this species. The arcuate form, small size, and the position of the spines accord well with the description given by Hall.

Genus STROPHALOSIA King.

90. Strophalosia truncata Hall.

(*Productella truncata*) Pal. N. Y., vol. 4, 1867, p. 160, pl. 23.

This species was found in the Marcellus shales and continued up into the barren shales of Zone E. In one layer in Zone C, a fraction of an inch thick, it occurs in great abundance. At Eighteenmile Creek it is found in the Marcellus shales and rarely in the next zone above.

Family ORTHIDÆ Woodward.

Genus RHIPIDOMELLA Oehlert.

91. Rhipidomella vanuxemi Hall.

(*Orthis vanuxemi*) Pal. N. Y., vol. 4. 1867, pp. 40, 47, pl. 5.

This is a very common species in the Upper Hamilton in the Cayuga Lake section, but was found in only one zone in the Lower Hamilton. It has the same range at Livonia as at Cayuga Lake, except that it is not reported from the shales below the Encrinal.

At Eighteenmile Creek it is one of the commonest fossils in the Lower Hamilton and is found rarely, and in but one zone, above the Encrinal.

At Cayuga Lake, with the exception mentioned above, no rhipidomellas are found in the Lower Hamilton. This is true of the Livonia section with the exception of *R. lenticularis* (?), which is reported as common in a mixed Onondaga (Corniferous) and Hamilton faunule at the base of the Lower Hamilton.

92. Rhipidomella cyclas Hall.

Pal. N. Y., vol. 4, 1867, p. 52, pl. 7.

One specimen from Zone T was identified as this species. The striæ are sharper and fewer and the hinge line longer than in the small forms of *R. vanuxemi*.

93. Rhipidomella penelope Hall.

Pal. N. Y., vol. 4, 1867, p. 50, pl. 6.

One specimen from Zone Y is referred to this species because of its larger size. The surface markings were obliterated. It may prove to be a large individual of *R. vanuxemi*.

This species is common at Kashong and Eighteenmile creeks.

Superfamily PENTAMERACEA Schuchert.

Family PENTAMERIDÆ McCoy.

Genus PENTAMERELLA Hall.

93a. Pentamerella pavilionensis Hall.

Pal. N. Y., vol. 4, 1867, p. 377, pl. 58.

A few badly crushed specimens of this species were found in the lower portion of Zone D. It is not uncommon in the Encrinal beds of the Seneca Lake section.

Subkingdom MOLLUSCA.

Class PELECYPODA Goldfuss.

The Pelecypoda in this paper are classified according to Dall, as given in Eastman's translation of Zittel's "Text Book of Palæntology," 1900. Genera which are not mentioned in the text-book are placed with the most closely allied forms. Such additions are indicated by a question mark before each genus so referred.

Adjustment to environment.—The Pelecypoda of the Hamilton seemed to be very much less closely adjusted to their environment than the Brachiopoda, as is shown by the fact that an apparently slight change of environment was sufficient to produce a great abundance or almost total extinction of certain genera of Brachiopoda, whereas the Pelecypoda often survived several changes of these brachiopod faunules and were never abundant.

Order PRIONODESMACEA Dall.

Family SOLEMYACIDÆ Dall.

Genus PHTHONIA Hall.

94. Phthonia nodicostata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 474, pl. 78.

Two specimens of this species were found in Zone M. They measured 23 and 20 mm. in length.

95. Phthonia cylindrica Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 473, pl. 78.

A single individual of this species was found in each of three zones. Two of these measured 17 and 21 mm. in length, and 8 and 10 mm. in height, respectively.

96. Phthonia sectifrons Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 475, pl. 78.

A right valve of this species, with the surface markings well preserved, was found in Zone Y.

Family SOLENOPSIDÆ Neumayr.

Genus ORTHONOTA Conrad.

97. Orthonota carinata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 479, pl. 78.

This well-marked species was found rarely in two zones in the Upper and two in the Lower Hamilton.

98. Orthonota undulata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 478, pl. 78.

This species was found in both the Upper and Lower Hamilton. Five specimens measured 64, 62, 57, 40, and 27 mm. in length and 16, 15, 15, 10, and 8 mm. in height, respectively.

99. Orthonota (?) parvula Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 482, pls. 65, 78.

This species is rare in every part of the section, but is found in a number of zones in both the Upper and Lower Hamilton above Zone D. At Livonia it was found in the upper 160 feet of the Hamilton and in one other zone above the Encrinal.

Genus PROTHYRIS Meek.

100. Prothyris lanceolata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 460, pl. 76.

This is a very rare species in this section. The largest specimen measured 25 mm. in length and 10 mm. in height, the smallest about 10 mm. in length and 2½ mm. in height.

101. Prothyris truncata sp. nov.

Shell small, rectangulate, length more than twice the height. Basal margin nearly straight and truncate behind, cardinal line long, straight, essentially parallel to the basal margin. Anterior end limited from the body by a low, narrow fold. Valves almost flat. Beaks very inconspicuous. A well-marked diagonal ridge is situated slightly posterior to the beak. Shell marked by faint concentric striæ, which are somewhat fasciculate along the basal margin.

Three specimens measured 13, 11, and 10 mm. in length, and 5, 3, and 3 mm., respectively, in height.

This species differs from *P. lanceolata* in its truncated posterior extremity and in the diagonal ridge; from *P. planulata* in the flatness of the valves and the absence of an angular umbonal slope.

Family GRAMMYSIIDÆ Fischer.

Genus GRAMMYSIA de Verneuil.

102. Grammysia constricta Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 377, pls. 59 and 78.

This species is rare throughout the section, and was not found below Zone D. The surface markings vary from almost continuous radiating lines to widely separated pustules, which can hardly be said to present a radiating appearance.

103. Grammysia cuneata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 383, pls. 62 and 93.

This species, like all species of *Grammysia*, is far from common in any portion of the section.

104. Grammysia arcuata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 373, pls. 61, 63, and 93.

Ten or 15 feet below the Encrinal this species is quite common, elsewhere it is rare. Three valves (one of which measures fully 80 mm. in length) from Zone Y answer the description of *G. subarcuata* of the Chemung fairly well, but were included in *G. arcuata*.

105. Grammysia bisulcata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 359, pls. 56 and 93.

A few specimens of this species were found in Zone G. It is reported from the upper 160 feet of the Upper Hamilton at Livonia.

Genus ELYMELLA Hall.

106. Elymella fabalis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 502, pl. 40.

Two valves from Zone Y are referred to this species. The anterior end is rather too long for *E. fabalis*, but may be a variation.

107. Elymella nuculoides Hall.

Pal. N. Y., vol. 5, pt. 1, p. 503, pl. 40.

A few specimens of this species were found in Zone X.

Genus GLOSSITES Hall.

108. Glossites subtenuis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 495, pl. 40.

There is some doubt as to the correctness of the identification of the specimen referred to this species.

Genus TELLINOPSIS Hall.

109. Tellinopsis subemarginata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 464, pl. 76.

This species is common in Zone X, the center of Zone T, Zone J, Zone G, and the lower portion of Zone D. It is never abundant and seldom common, but is found in almost all the zones in this section.

At Eighteenmile Creek a single specimen was found. It is reported from four zones in the Upper Hamilton of the Livonia section.

Two large specimens were 45 and 30 mm. long and 27 and 17 mm. [redacted]

Family CARDIOLIDÆ Neumayr.

Genus PANENKA Barrande.

110. Panenka lincklæni Miller.

Pal. N. Y., vol. 5, pt. 1, p. 420, pl. 69.

The specimen which was referred to this species is probably a new species. It differs from *P. lincklæni* in the broad concave plications, the almost flat interspaces, and the absence of intermediate radii. Both plications and interspaces are crossed by fine concentric lines. Found in Zone T.

111. Panenka potens Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 422, pl. 69.

A very imperfect specimen about 60 mm. in height is doubtfully referred to this species. It was found associated with *Lunulicardium curtum* and *L. ornata* in Zone C.

112. Panenka sp. undet.

A small, well-preserved cast of a *Panenka* from Zone X does not answer the description given in the New York Paleontology. It is about 12 mm. high and of the same length. The plications number 22 and reach the beak. Faint concentric lines can be seen. This specimen bears a resemblance to *P. retusa*, which is reported from Cayuga Lake. The plications of *P. retusa*, however, number 35, with narrow interspaces, while the size is 30 mm. in length and 31 mm. in height.

Genus GLYPTOCARDIA Hall.

113. Glyptocardia speciosa Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 426, pls. 70 and 80.

This species is found occasionally in Zones T, F, and E; elsewhere in the section it is very rare or wanting. The largest specimen from Zone F measured 11 mm. in height. It is not reported from Eighteen-mile Creek or Livonia.

Superfamily NUCULACEA.

Family (?) CTENODONTIDÆ Dall.

Genus NUCULITES Conrad.

114. Nuculites triqueter Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 326, pls. 47 and 93.

This species is common throughout the section, except where the shales are calcareous, as in the Encrinal bed, Zone D and Zone G. The variations in form are not progressive. It is not uncommon at Livonia, but was not found above the Marcellus shale at Eighteen-mile Creek.

115. **Nuculites oblongatus** Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 324, pl. 47.

What has been said regarding the distribution of *N. triqueter* in the Cayuga Lake section is true of *N. oblongatus*. The conditions which were favorable to one were favorable to the other.

At Eighteenmile Creek it is rare in the only zone in which it occurs.

Family NUCULIDÆ Adams.

Genus NUCULA Lamarck.

116. **Nucula varicosa** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 319, pls. 46 and 93.

This is a very variable species, the extremes of which are often difficult to classify. It is one of the rarer nuculas.

117. **Nucula randalli** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 315, pls. 45 and 93.

A small *Nucula* from Zone I was referred doubtfully to this species.

118. **Nucula lirata** Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 316, pls. 45 and 93.

This is a common species in the Upper but is not often found in the Lower Hamilton in this section. It is reported from two zones in the Upper Hamilton at Livonia. It does not occur at Eighteenmile Creek.

119. **Nucula bellistriata** Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 318, pl. 46.

This species is so closely related to *N. varicosa* that in some cases it is difficult to distinguish between them. It is not uncommon between Zone D and the Tully limestone, but is never abundant.

120. **Nucula corbuliformis** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 319, pl. 46.

This is more common and has a greater vertical distribution than any other *Nucula* in the section. It is found throughout the Marcellus and Hamilton shales along Cayuga Lake. Unlike the Brachiopoda, it is present in almost every zone except those which are very calcareous, as the Encrinal, and, although it is never exceptionally abundant in the aggregate, the number of individuals is very great.

Family LEDIDÆ Adams.

Genus LEDA Schumacher.

121. Leda rostellata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 330, pl. 47.

This species is common in the *Stropheodonta*-Coralline zone, but is rare elsewhere in the section. It was not found in the Marcellus shales or Zone C. It is not reported from Livonia or Eighteenmile Creek.

122. Leda brevirostris Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 329, pl. 47.

Specimens from Zone Y were referred to this species.

Genus PALÆONEILO Hall.

123. Palæoneilo constricta Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 333, pls. 48 and 51.

P. constricta is a common and sometimes an almost abundant species throughout the greater portion of the section above Zone D. It was also found in the upper part of Zone C. Its greatest abundance is in Zone T.

124. Palæoneilo emarginata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 338, pl. 50.

This strongly marked species is common in Zone W, in the lower part of Zone T, and in Zone I; elsewhere in the section it is very rare.

125. Palæoneilo plana Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 334, pl. 48.

This species was not found below Zone R. It is quite common in Zone W and in the upper part of Zone T.

126. Palæoneilo maxima Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 335, pl. 48.

A single specimen from Zone Y was referred to this species. It measured 34 mm. in length by 19 mm. in height.

127. Palæoneilo muta Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 337, pl. 49.

This species was found only in the Upper Hamilton, and then but rarely. Three specimens measured 19, 16, and 10 mm. in length and 11, 8, and 5 mm. in height, respectively.

128. Palæoneilo fecunda Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 336, pl. 49.

This is a rare species in this section. With the exception of a single specimen from Zone I, it is only found, and rarely, in the Upper Hamilton.

129. Palæoneilo tenuistriata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 336, pls. 49 and 93.

This species is restricted to a narrow zone in the Upper Hamilton of which Zone W is the center. One specimen, which retains a portion of the shell, shows radiating lines apparently due to the original color of the shell. Other specimens show faint radiating lines.

Family PARALLELODONTIDÆ Dall.

Genus PARALLELODON Meek.

130. Parallelodon hamiltoniæ Hall.

(*Macrodon hamiltoniæ*) Pal. N. Y., vol. 5, pt. 1, 1885, p. 349, pl. 51.

This species is quite common from Zone D to the Tully limestone. It was found in Zones B and C.

(?) Genus SPHENOTUS Hall.

131. Sphenotus arcæformis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 395, pls. 65 and 66.

A small specimen of this species from Zone K measured 9 mm. in length and 4 mm. in height. The normal size is 26 to 32 mm. in length and 12 to 14 mm. in height.

132. Sphenotus cuneatus Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 396, pl. 65.

Four well-marked specimens of this species were found in Zone G. The specimens measured 19, 15, 16, and 6 mm. in length and 9, 8, 8, and 4 mm., respectively, in height.

133. Sphenotus solenoides Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 398, pl. 45.

This is a rare species in this section. It was found in Zones D and L.

Superfamily PTERIACEA Dall.

Family PTERINEIDÆ Dall.

Genus PTERINEA Goldfuss.

134. Pterinea flabella Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 93, pls. 14 and 15.

This species was not found in the Upper Hamilton and is very rare in the Lower Hamilton, being common in no zone. At Eighteenmile Creek it is found commonly a few feet below the Encrinal beds, but is not reported above.

Family LUNULICARDIIDÆ Fischer.

Genus LUNULICARDIUM Münster.

135. **Lunulicardium fragile** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 434, pl. 71.

This species, with the exception of Zone D, is not uncommon between Zones A and G. Above Zone G it is rarely found. At Eighteenmile Creek it is reported from but one zone above the Marcellus shale. At Livonia it is a common fossil below the Encrinal, and is abundant in one zone of the Upper Hamilton.

136. **Lunulicardium curtum** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 437, pl. 71.

This occurs rarely in the shales of Zone C and the Marcellus.

137. **Lunulicardium ornatum** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 437, pl. 71.

This species was found in the upper part of Zone C.

Family AMBONYCHIIDÆ Miller.

Genus PLETHOMYTILUS Hall.

138. **Plethomytilus oviformis** Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 255, pls. 31 and 87.

This species was found in Zones I, F, X, and Y. The specimens measured 62, 32, and 8 mm. in height, and 50, 26, and 6 mm. in length. At Eighteenmile Creek it is restricted to the upper Encrinal beds.

Genus MYTILARCA Hall.

139. **Mytilarca gibbosa** Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 262, pls. 33 and 87.

The specimen which was referred provisionally to this species is about midway between *M. gibbosa* and *M. simplex* in form. It measures 35 mm. in height and 24 mm. in length.

Genus SPATHELLA Hall.

140. **Spathella typica** Hall.

Pal. N. Y., vol 5, pt. 1, 1885, p. 407, pl. 66.

This specimen is 28 mm. in length and 14 or 15 mm. in height. It is slightly crushed dorso-ventrally. The concentric lines are strong, with occasional finer concentric striæ between.

Family CONOCARDIIDÆ Neumayr.

Genus CONOCARDIUM Bronn.

141. Conocardium normale Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 411, pl. 68.

A single specimen of this genus was found in Zone I. The surface markings on the posterior and the anterior expansion of the shell along the edge of the umbonal ridge can be made out.

Family PTERIIDÆ Meek.

Subgenus ACTINOPTERIA Hall.

142. Actinopteria boydi Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 113, pls. 19 and 84.

This is a rare fossil in this section. It is found occasionally in the limy shales of Zones Y and D.

143. Actinopteria decussata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 111, pls. 17, 18, 20, and 84.

A few specimens of this species were found in the Upper Hamilton.

144. Actinopteria subdecussata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 110, pls. 17 and 19.

A single specimen was found in Zone T.

Genus LEIOPTERIA Hall.

145. Leiopteria greeni Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 160, pls. 20 and 88.

A single specimen of this species was found in Zone L. It measured 38 mm. in height and 32 mm. along the hinge line.

146. Leiopteria lævis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 158, pls. 17 and 20.

This species is common in the Upper Marcellus, seldom found in Zone C, and occasionally in the shales above Zone D.

147. Leiopteria rafinesquii Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 161, pls. 15, 20.

Specimens from Zones J and D belong to this species.

148. Leiopteria gabbi Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 169, pl. 88.

One individual of this species was found in Zone C. One from Zone T was referred to it with some doubt.

149. Leiopteria sayi Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 162, pl. 88.

This species is rather common in Zone T, but not elsewhere in the section. It is associated with *L. lævis*.

150. Leiopteria conradi Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 159, pls. 20 and 88.

A number of specimens from Zones D and T were of this species. A number of intermediate forms were included.

151. Leiopteria dekayi Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 164, pls. 19, 20, 88.

One specimen from Zone T was of this species. It was not perfect, but the obliqueness of the form, which is very characteristic of *L. dekayi*, is quite pronounced.

Family MYALINIDÆ Frech.

Genus MODIELLA Hall.

152. Modiella pygmæa Conrad.

Pal. N. Y., vol. 5, pt. 1. 1885, p. 514, pl. 76.

This species is found occasionally in Zone C and is one of the common fossils from Zone D to within a foot of the Tully limestone. It reaches its greatest abundance in Zone T. It has very much the same habit as *Nuculites oblongatus* and *N. triqueter*. Although seldom common, it is almost always present except in very limy sediments.

Superfamily TRIGONIACEA Bronn.

Family TRIGONIIDÆ Lamarck.

Genus SCHIZODUS King.

153. Schizodus appressus Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 449, pl. 75.

This is a rare species, but is not confined to any one zone.

154. Schizodus contractus Hall.

Pal. N. Y., vol. 5, pt. 1, p. 451, pl. 75.

Specimens of this species were found in the shales immediately under the Tully limestone and in Zone D. Between these zones it is wanting. One individual measured 4 mm. in height and 7 mm. in length.

Superfamily PECTINACEA Reeve.

Family PECTINIDÆ Lamarck.

Genus AVICULOPECTEN McCoy.

155. Aviculopecten princeps Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 1, pls. 1, 5, 6, 24, and 81.

This species is from the upper and lower portions of the Upper Hamilton. It seemed to thrive best in calcareous sediments. One right valve had markings similar to those shown in pl. 81, fig. 16. It was found in six zones at Eighteenmile Creek.

156. Aviculopecten fasciculatus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 11, pls. 5 and 81.

One imperfect specimen from Zone D was doubtfully referred to this species.

157. Aviculopecten scabridus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 7, pl. 3.

A very much distorted specimen with the characteristic surface markings was found in Zone G.

Subgenus Pterineopecten Hall.

158. Pterineopecten undosus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 72, pls. 2 and 82.

This species is restricted to the Upper Hamilton and the upper 50 feet of the Lower Hamilton. It is nowhere common, and varies greatly in shape and surface markings.

159. Pterineopecten vertumnus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 71, pls. 5 and 83.

This species is found in three zones, only one specimen being found in each.

160 Pterineopecten intermedius Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 68, pls. 17 and 83.

This species is slightly commoner than the preceding species of *Pterineopecten*, and is found in a number of zones from Zone D to the Tully.

161. Pterineopecten hermes Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 64, pl. 17.

This is a well-marked but variable species, and when poorly preserved often resembles *P. intermedius*.

Subgenus LYRIOPECTEN Hall.

162. Lyriopecten orbiculatus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 42, pls. 4 and 82.

A specimen from Zone D was referred with considerable certainty to this genus and species.

Superfamily MYTILACEA Ferussac.

Family MODIOLOPSIDÆ Fischer.

Genus MODIOMORPHA Hall.

163. Modiomorpha subalata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 283, pls. 35 and 39.

This species is not uncommon in Zones J, F, and the upper part of C. Four specimens measured, respectively, 19, 21, 24, and 32 mm. in length and 11, 12, 15, and 18 mm. in height. It is a common species in the Lower Hamilton at Eighteenmile Creek.

164. Modiomorpha concentrica Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885. p. 275, pls. 34, 35, 36.

This is the commonest *Modiomorpha* at Cayuga Lake. It is distributed from Zone D to the uttermost zone in the Hamilton. It is common in Zones H, O, T, and X. At Eighteenmile Creek it is common in the Encrinal and is found occasionally in the Lower, but does not occur in the Upper Hamilton.

165. Modiomorpha mytiloides Conrad.

Pal. N. Y., vol. 5, pt. 1, p. 277, pls. 37 and 38.

This species is far from being common, but is found occasionally in Zone D and above. It is common in three zones above the Encrinal at Livonia, but it is not reported from Eighteenmile Creek.

166. Modiomorpha alta Conrad.

Pal. N. Y., vol. 5. pt. 1, 1885, p. 278, pls. 37, 80.

Two small specimens from Zone X were referred to this species. A number of specimens which seem to be of a new species have been placed in this species. The measurements of these were 25, 18, 15, 10, and 4 mm. in length and 16, 11, 11, 7, and 5 mm. in height.

Genus GONIOPHORA Phillips.

167. Goniophora hamiltonensis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 296. pl. 43.

This species is found rarely in eight zones, commencing with the first *Terebratula* zone (D), to the Tully limestone.

168. Goniophora truncata Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 298, pls. 42 and 44.

This well-marked species was found in Zones S and Y. Only one specimen was found in each zone and both were badly crushed.

169. Goniophora rugosa Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 297, pls. 42 and 43.

A few specimens of this species were found between Zone D and the Tully limestone. Two specimens measured 40 and 45 mm. in length and 26 and 28 mm. in height, respectively.

170. Goniophora glaucus Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 299, pls. 43 and 44.

A single badly crushed specimen from Zone Y was referred to this species with doubt.

Order ANOMALODESMACEA Dall.

Superfamily ANATINACEA Dall.

Family PHOLADELLIDÆ Miller.

Genus PHOLADELLA Hall.

171. Pholadella radiata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 469, pls. 78 and 96.

This species was not found in the Marcellus shales nor in Zone C, but is scattered throughout the remainder of the section. It occurs frequently in the upper shales of the Lower Hamilton and is almost abundant in Zone O.

Three specimens measured 25, 7 and 5 mm. in length and 13, 4, and 2 mm. in height, respectively.

172. Pholadella parallela Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 470, pl. 78.

This well-marked species was found in Zone T. It is rare in this zone and was not obtained elsewhere in the section.

Genus CIMITARIA Hall.

173. Cimitaria corrugata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 465, pl. 77.

This species was found in Zones Y and H, but was not seen elsewhere in the section.

174. Cimitaria elongata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 466, pl. 77.

Two specimens of this species were obtained from the Encrinal band at King Ferry.

Order TELEODESMACEA Dall.

Superfamily CYPRICARDIACEA Dall.

Family PLEUROPHORIDÆ Dall.

Genus CYPRICARDELLA Hall.

175. Cypricardella bellistriata Conrad.

(*Microdon bellistriatus*) Pal. N. Y., vol. 5, pt. 1, 1885, p. 308, pls. 42, 73, 74.

This species is common in the upper part of the Upper Hamilton and in the upper portion of the Lower Hamilton; in the latter it is almost abundant. Aside from these two zones the species is quite rare in this section.

At Eighteenmile Creek it was not found above the Encrinal and, with the exception of one zone at the base of the Hamilton, is very rare throughout the section. One very large specimen from the Encrinal bed on Paines Creek measured 60 mm. in length and 38 mm. in height.

Genus CYPRICARDINIA Hall.

176. Cypricardinia indenta Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 485, pls. 79 and 96.

This species is common in two zones, in Zone X and the middle third of Zone D.

Specimens measured 14, 9, and 7 mm. in length and 8, 5, and 4 mm. in height, respectively. It is a Lower Hamilton fossil at Eighteenmile Creek.

Superfamily LUCINACEA Anton.

Family LUCINIDÆ Fleming.

Genus PARACYCLAS Hall.

177. Paracyclas tenuis Hall.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 443, pls. 72 and 95.

This species is rather common in three zones of the Upper and in one zone of the upper part of the Lower Hamilton. It varies greatly in size and in the strength of its concentric striæ, but is readily distinguished from the other species of this genus. It is not reported from Eighteenmile Creek or Livonia.

178. Paracyclas lirata Conrad.

Pal. N. Y., vol. 5, pt. 1, 1885, p. 441, pls. 72 and 95.

Only two small valves of this species were found. They measured about 7½ mm. in height by 8 mm. in length.

Class GASTEROPODA.

The Gasteropoda were not found to be of much value in this faunal study. They are never common, but are found occasionally in almost all of the zones.

Subclass STREPTONEURA Spengel.

Order ASPIDOBRANCHIA Schweigger.

Suborder RHIPIDOGLOSSA Troschel.

Family PLEUROTOMARIIDÆ d'Orbigny.

Genus PLEUROTOMARIA de France.

179. Pleurotomaria itys Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 76, pl. 20.

As with the other species of the genus, *P. itys* is not common in nor charactistic of any zone. It occurs throughout the section. At Eighteenmile Creek it is found only at the base of the Hamilton.

180. Pleurotomaria capillaria Conrad.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 77, pl. 20.

It is often difficult to distinguish the extremes of this species from the above unless the specimens are well preserved. Quite generally distributed throughout the section. Confined to the base of the Hamilton at Eighteenmile Creek.

181. Pleurotomaria trilix Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 79, pl. 21.

Found rarely in the Upper Hamilton at Cayuga Lake.

182. Pleurotomaria sulcomarginata Conrad.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 69, pl. 19.

Two specimens of this species were obtained from the upper part of the Upper Hamilton, Zones W and T.

183. Pleurotomaria rotalia Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 71, pl. 19.

Two specimens from Zone T were of this species.

184. Pleurotomaria rugulata Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 75, pl. 20.

This species is met with occasionally in Zone C, in the Marcellus shales, and in Zone D. The specimens are all very much crushed or in the form of molds, and the surface markings are indistinct.

Family BELLEROPHONTIDÆ McCoy.

Genus BELLEROPHON de Montfort.

185. Bellerophon patulus Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 100, pls. 22 and 24.

This species is not uncommon in Zones X and N; elsewhere it is rare. It was not found below Zone C. The specimens obtained were of the usual size, but badly crushed.

186. Bellerophon leda Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 110, pl. 23.

This is the most common Bellerophon in the section. It is almost common in some of the thin layers of Zone C. It is common in the lower portion of the Lower Hamilton at Eighteenmile Creek.

187. Bellerophon lyra.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 113, pl. 23.

Only a few specimens of this species were found in the section.

188. Bellerophon crenistria Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 116, pl. 25.

A few specimens of this species were obtained in six zones of the Upper and Lower Hamilton.

Genus CYRTOLITES Conrad.

189. Cyrtolites mitella Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 123, pl. 25.

Only a few specimens of this species were obtained. None were found lower than Zone D.

Family EUOMPHALIDÆ de Koninck.

Genus EUOMPHALUS Sowerby.

190. Euomphalus sp.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 54.

A single crushed specimen from Zone O was referred to this genus. The specific characters could not be made out.

Order CTENOBRANCHIATA Schweigger.

Suborder PLATYPODA.

Superfamily TÆNIOGLOSSA Bouvier.

Family CAPULIDÆ Cuvier.

Genus PLATYCERAS Conrad.

191. Platyceras conicum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 3, pl. 1.

A single large specimen was found in the Encrinal beds.

192. Platyceras erectum Hall

Pal. N. Y., vol. 5, pt. 2, 1879, p. 5, pl. 2.

This gastropod was found most commonly in the upper portion of the Encrinal and in the limestone of Zone Y. Elsewhere it is rare.

193. Platyceras bucculentum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 10, pl. 3.

Typical specimens of this species were found in Zones Y and S.

194. Platyceras carinatum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 5, pl. 2.

Specimens having the characteristic shape of this species were found in Zones W and Y.

Genus PLATYOSTOMA Conrad.

195. Platyostoma lineata Conrad.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 21, pl. 10.

This species was found in a number of zones, but was not common in any. It possesses, in all cases, the characteristic surface markings.

196. Platyostoma varians Hall.

(*Strophostylus*) Pal. N. Y., vol. 5, pt. 2, 1879, p. 31, pl. 11.

A large specimen from Zone J and eight smaller ones from Zone C were referred to this species with some doubt. The larger specimen is typical; the smaller ones are small, and may be of a new species.

Superfamily GYMNOGLOSSA.

Family PYRAMIDELLIDÆ Gray.

Genus LOXONEMA Phillips.

197. Loxonema hamiltoniæ Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 45, pl. 13.

This species occurs throughout the entire section. It is often difficult to distinguish it from *L. delphicola* when the specimens are imperfect. At Eighteenmile Creek this species and *L. delphicola* are restricted to the Upper Marcellus shales.

198. Loxonema delphicola Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 47, pls. 13 and 14.

This species is frequently met with in the section above Zone D. It is commoner than *L. hamiltoniæ*. Very often the shell is surrounded by a "smooth, polished shale (slickensides)," as is figured by Hall in figs. 24 and 25 of the above report.

Superfamily PTENOGLOSSA Gray.

Family SCALARIIDÆ Broderip.

Genus CALLONEMA Hall.

199. Callonema imitator Hall and Whitfield.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 53, pl. 14.

One specimen, 50 mm. in diameter, with the surface marked by strong elevated striae gently curving backward and increasing in strength from the apex to the last volution, was found in Zone N. The coil is rather loose.

Order OPISTHOBRANCHIA Milne-Edwards.

Suborder PTEROPODA Cuvier.

Family CAVOLIINDÆ Fischer.

Subgenus STYLIOLA Lesueur.

200. Styliola fissurella Hall.

Pal. N, Y., vol. 5, pt. 2, 1879, p. 178, pl. 31A.

It will be noticed in the table of species that *S. fissurella* is very rare, almost wanting, in the Upper Hamilton; that between Zone D and the Encrinal, with the exception of the fine shales of Zone E, it is also very rare, and that in the fine shales of Zone C and in the Marcellus shales it is very common. In the lower portion of the Marcellus shales the *Styliola* is beautifully preserved in pyrite. It is very abundant in certain layers in the Marcellus shales. At Eighteenmile Creek it is very common in a number of zones of the Lower and is fairly common in the uppermost zone of the Upper Hamilton.

Suborder CONULARIDA Miller and Gurley.

Family TENTACULITIDÆ Walcott.

Genus TENTACULITES Schlotheim.

201. Tentaculites bellulus Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 169, pls. 31 and 31A.

A specimen of this species was obtained from Zone X. In Zone A there are great numbers of *Tentaculites*, but in such a poor state of preservation that it is impossible to make a specific identification.

Family TORELLELLIDÆ Holm.

Genus COLEOLUS Hall.

202. Coleolus tenuicinctum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 185, pls. 32 and 32A.

A number of very good specimens of this species were found in various parts of the section.

Family HYOLITHIDÆ Nicholson.

Genus HYOLITHES Eichwald.

203. Hyolithes aclis Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 197, pls. 32 and 32A.

Although this is a rare species at Cayuga Lake, in the aggregate the number found is quite large. The variations consist in the relative difference in length, width, and thickness. The measurements are 30, 30, 25 mm. in length and 9, 11, and 12 mm. in width. Two well-preserved operculæ were found.

204. Hyolithes striatus Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 199, pl. 32.

A specimen with well-marked longitudinal lines was found in Zone T.

Genus CONULARIA Miller.

205. Conularia undulata Conrad.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 208, pls. 33 and 34A.

A fragment of a large specimen of this species with very strong surface markings was found in Zone D. A fragment of a smaller individual was taken from Zone I.

Class CEPHALOPODA.

Subclass TETRABRANCHIATA Owen.

Order NAUTILOIDEA.

Suborder ORTHOCHOANITES Hyatt.

Family ORTHOCERATIDÆ.

Genus ORTHOCERAS Breynius

206. Orthoceras crotalum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 296, pls. 42, 82, and 93.

This fossil is found occasionally throughout the section above Zone D. The test is often denuded, making the identification in some cases uncertain.

207. Orthoceras cælamen Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 298, pls. 42, 43, 82, 113.

A few specimens with the characteristic surface marking were obtained from the Upper Hamilton shales.

208. Orthoceras nuntium Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 299, pls. 43 and 82.

This is a rare fossil in this section. Two specimens were found in the Upper Hamilton.

209. Orthoceras subulatum Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 283, pls. 38, 84, 86.

This species of *Orthoceras* is not uncommon along Cayuga Lake. A large number of distorted specimens of this genus were referred here with some doubt. One specimen showed the surface markings.

210. Orthoceras constrictum Vanuxem.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 288, pls. 84, 85.

This is a rather rare species in this section, and is not reported west of Cayuga Lake.

211. Orthoceras exile Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 290, pls. 39, 84, 85.

A few specimens were doubtfully placed in this species.

212. Orthoceras marcellense Vanuxem.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 278, pls. 38, 83, and 113.

A specimen from the Marcellus seems to be of this species.

213. Orthoceras, sp. undet.

This genus, as a whole, is common between Zones B and F, inclusive, and in Zone T. Elsewhere in the section this genus was rare.

Family NAUTILIDÆ.

Genus NAUTILUS Breyn.

214. Nautilus liratus juvenis Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 411, pl. 56.

James Hall describes this variety of *N. liratus* from an imperfect specimen and states that the determination is quite unsatisfactory. Two fairly well-preserved specimens from the hard shales of the upper Marcellus are certainly distinct from *N. liratus* and answer to the description of *N. liratus juvenis*. The difference between these specimens and *N. liratus*, however, seems to be specific rather than varietal.

215. Nautilus, fragments.

A number of fragments of *Nautilus* found in various parts of the section were too imperfect for specific identification.

Suborder CYRTOCHOANITES Hyatt.

Family PHRAGMOCERATIDÆ.

Genus GOMPHOCERAS Sowerby.

216. Gomphoceras, sp.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 318.

A single crushed specimen of this genus was found in Zone C. The markings were obliterated to such an extent that it was impossible to make a specific identification.

Order AMMONOIDEA.

Suborder EURYCAMPYLI Hyatt.

Family GLYPHIOCERATIDÆ.

Genus GONIATITES de Haan.

217. Goniatites discoideus Hall.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 441, pls. 71, 74.

Casts of the test showing the fine, closely arranged striæ, "raised at intervals in fascicles," were commoner than those showing the septa. This species was fairly common in Zone T. In Zone I a number of imperfect specimens which were either of this species or of *G. uniangularis* were quite frequently found. Elsewhere in the section they are very rare.

218. Goniatites uniangularis Conrad.

Pal. N. Y., vol. 5, pt. 2, 1879, p. 444, pls. 71, 74.

This species was very rare, but several well-preserved specimens were found. One almost perfect small specimen from the lower shales of Zone C measured 15 mm. in diameter in the widest part. A large specimen measured 45 mm. in diameter.

Subkingdom ARTHROPODA.

Class CRUSTACEA.

Subclass TRILOBITA.

Order OPISTHOPARIA Beecher.

Family PRÖETIDÆ Barrande.

Genus PRÖETUS Steininger.

219. Pröetus rowi Green.

Pal. N. Y., vol. 7, 1888, p. 119, pls. 21 and 23.

A portion of the cephalon with a crushed glabella and a perfect genal spine was referred, with some doubt, to this species.

220. Prœtus microgemma Hall.

Pal. N. Y., vol. 7, 1888, p. 109, pl. 22.

An imperfect pygidium was referred with considerable certainty to this species.

221. Prœtus macrocephalus Hall.

Pal. N. Y., vol. 7, 1888, p. 116, pls. 21 and 23.

A pygidium and thorax were found in Zone Y and a glabella in the Encrinal bed. The surface markings are quite plain.

Genus HOMALONOTUS Köenig.

222. Homalonotus dekayi Green.

Pal. N. Y., vol. 7, 1888, p. 7, pls. 2, 3, 4, 5.

This is quite a common fossil in the upper portion of the Encrinal band. A fragment of a pygidium was found in Zone Y and a portion of a cephalon in Zone D. At Eighteenmile Creek it is reported from the lower portion of the Lower Hamilton. In Kashong Creek it occurs rarely in the Upper Hamilton.

Order PROPARIA Beecher.

Family PHACOPIDÆ Salter.

Genus PHACOPS Emmrich.

223. Phacops rana Green.

Pal. N. Y., vol. 7, 1888, p. 19, pls. 7, 8, 8A.

This is a common and sometimes an abundant species in this section. Above the Encrinal it occurs in almost every zone. Occasionally a complete specimen was found. It is usually associated with *D. boothi* and *A. umbonata*.

224. Phacops cristata var. pipa Hall.

Pal. N. Y., vol. 7, 1888, p. 18, pl. 8.

A specimen of this variety was found in Zone A.

Genus DALMANITES Emmrich.

225. Dalmanites boothi Green.

Pal. N. Y., vol. 7, 1888, p. 42, pls. 16, 16A.

This species was found in the lowest portion of Zone C. It is common throughout the section from Zone D to the Tully, especially above the Encrinal.

At Eighteenmile Creek it is commonest below the Encrinal, while at Cayuga Lake the opposite is true.

226. Dalmanites boothi var. calliteles Green.

Pal. N. Y., vol. 7, 1888, p. 45, pls. 16, 16A.

A few specimens of this variety were found in the upper portion of the Upper Hamilton.

Subclass EUCRUSTACEA Kingsley.

Superorder MALACOSTRACA Latreille.

Order PHYLLOCARIDA Packard.

Suborder Ceratiocarina Clarke.

Family ECHINOCARIDÆ Clarke.

Genus ECHINOCARIS Whitfield.

227. Echinocaris punctata Hall.

Pal. N. Y., vol. 7, 1888, p. 166, pls. 27, 28, 29.

Five specimens of this species were found in the Cayuga Lake section, one in the Upper and four in the Lower Hamilton above Zone D.

Genus TROPIDOCARIS Beecher.

228. Tropidocaris hamiltoniæ Hall.

Pal. N. Y., vol. 7, 1888, pl. 30.

A right valve of this species was found in Zone O. It measured 10 mm. in length.

Suborder RHINOCARINA Clarke.

Family RHINOCARDIDÆ Clarke.

Genus RHINOCARIS Clarke.

229. Rhinocaris sp.

Pal. N. Y., vol. 7, 1888, p. lviii, pl. 31.

Two specimens of this genus, one with both valves, the other with one valve of the carapace were found in the shale of Zone C along Dean Creek. The preservation was too imperfect to permit of specific identification.

Genus MESOTHYRA Hall and Clarke.

230. Mesothyra oceani Hall.

Pal. N. Y., vol. 7, 1888, p. 187, pls. 33 and 34.

Two specimens of this genus were referred doubtfully to this species. Neither specimen is perfect enough to warrant a specific identification. The length of the carapace is 20 mm. and 45 mm., respectively.

231. Superorder OSTRACODA Latreille.

The various species and genera of this superorder seem to have been adapted to the same conditions of environment during the Hamilton stage. They are common in the fine shale of Zones B, C, and E.

PLANTÆ.

Genus LEPIDODENDRON Sternberg.

232. Lepidodendron gaspianum Dawson.

Quar. Jour. Geol. Soc., 1859, vol. 15, p. 484.

A specimen of this plant with distinct imprints of the leaves was found in Zone C.

Thanks is due Professor Penhallow for the identification.

233. Plant fragments.

Plants, usually in a poor state of preservation, were scattered throughout the section. Within a foot or two of the Tully limestone plant fragments were especially well preserved and abundant.

Genus TAONURUS.

234. Taonurus sp.? Fischer-Ooster.

This fucoid was very abundant in the upper portions of the Upper and Lower Hamilton.

CHAPTER V.

COMPARISON OF THE CAYUGA LAKE SECTION WITH OTHER SECTIONS OF THE HAMILTON FORMATION.

BASAL LIMESTONE.

The Basal limestones of Ontario County are described by J. M. Clarke, as follows:[a]

Within 10 feet of the top of the Marcellus shales, where the rocks still retain their characteristic color and diagnostic fossils, appear *Spirifer mucronatus* and *Ambocœlia umbonata* of the Hamilton fauna, such Hamilton species increasing in number and the rocks becoming less and less bituminous until at the top of 10 feet the bituminous character has disappeared and with it the Marcellus fauna. Overlying is a series of strata of limestone more or less impure and persisting throughout the county east and west.

Farther east the same strata become more shaly and lose many of the fossils of the richer western outcrop. Dr. D. F. Lincoln[b] accepted the term "Basal Hamilton," proposed by J. M. Clarke, and the description of Hall in the report of the Fourth District[c]—"a compact calcareous blue shale passing into an impure limestone." He says that it retains this character (of a coral reef) to some extent in Seneca County, displaying scattered fragments of *Heliophyllum*, *Favosites*, and other large corals which do not belong elsewhere in the region.

From the description given above and from its position in the section (see map Pl. I) it seems certain that the compact calcareous shales of Zone D should be correlated with the Basal Hamilton of Ontario and Seneca counties.[d] There is, however, considerable difference in the faunules. Although the corals are very much rarer in Zone D at Cayuga Lake compared with that stratum in the west, yet *Heliophyllum* is common only in this stratum in the Cayuga Lake section. This zone is characterized in Ontario County by a great abundance of Crustacea. The development of Crustacea in Zone D is by no means remarkable, only three species of trilobites being found, none of which were abundant.

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[a] Report State Geol., New York, 1885.

[b] Ibid., 1894.

[c] 1843.

[d] Since the above was written the author revisited the localities on Seneca Lake. There is no doubt as to the correctness of the correlation.

A comparison of the Basal Hamilton of Ontario County, Seneca County, and Zone D of Cayuga Lake shows a decrease in the amount of calcareous matter and in corals from west to east. It is probable that the region along Cayuga Lake was the edge of the reef, if such it can be called, and that the conditions were such that most of the species of corals and Crustacea which flourished so well in the west were represented in the Cayuga Lake region by an abundant brachipod and pelecyopod fauna, with here and there a large *Heliophyllum halli* and a colony of *Syringopora.*

This impure limestone layer, the Basal Hamilton, is, next to the Encrinal beds, the most persistent stratum in the New York Hamilton, extending as it does for more than 40 miles from east to west.

I. P. Bishop, in the Geology of Erie County, mentions[a] a calcareous stratum in that county which he correlated provisionally with the Basal limestone of Clarke. The evidence for this correlation is so unsatisfactory that it must be disregarded.

ENCRINAL BEDS.

In comparing the faunules of the Encrinal beds with that of Eighteenmile Creek, it was found that of 8 lamellibranchs of the Eighteenmile Creek Encrinal 4 are found in the Encrinal of the Cayuga Lake section, 2 are extremely rare, and 2 have been found nowhere in this section. Of the 35 brachiopods, 13 were not found in the Encrinal of Cayuga Lake. But of that number 4 have not been found elsewhere in the section and 4 are extremely rare. *Vitulina pustulosa*, *Centronella impressa*, *Meristella haskinsi*, and *Heliophyllum confluens* are restricted to the Encrinal at Eighteenmile Creek. With the exception of *V. pustulosa* and *M. haskinsi*, which was found in the Encrinal and Zone D, these species are restricted to the Encrinal at Cayuga Lake. Grabau[b] finds the Encrinal at Eighteenmile Creek to be the equivalent of that at Livonia. The comparison of the fossils from that stratum in the two places brings out the fact that only one species given in the Livonia list is wanting in the limestone at Eighteenmile Creek. James Hall[c] considered the Encrinal as a "persistent mass holding only one position in the group and continuous as far as Lake Erie. It is a convenient point of reference." It is 1½ feet thick at Lake Erie, 2 feet at Livonia, 3 feet in Yates County, and 1½ feet in Cayuga County.

Prof. C. S. Prosser,[d] in discussing Professor White's correlation of a zone in eastern Pennsylvania which is as rich in corals and crinoids as the Tully, shows by the fossil content that the Genesee shales of White are Hamilton shales. The so-called Tully does not contain any

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[a] Report State Geol. New York, 1895.
[b] Report State Geol. New York, 1898.
[c] Report Fourth District New York, 1843.
[d] Bull. U. S. Geol. Survey No. 120, 1894, p. 74.

characteristic Tully fossils, but contains only Hamilton species. He says:

If a correlation of this zone with one of central and western New York were attempted, I would suggest the Encrinal limestone separating the fossiliferous argillaceous Ludlowville and Moscow shales. As the Pennsylvania horizon may be represented by any one of the several coral horizons in the Hamilton of New York or by an entirely different one, such a correlation of this zone is very hazardous without careful comparison of the species and stratigraphy.

On the east shore of Skaneateles Lake, 2½ miles from the head of the lake, is a bed of cyathophylloid and other genera of corals 5 feet thick, which are described by Luther.[a] Luther concludes, from its position and from the fact that it "abounds in cyathophylloid corals which characterize the Encrinal of the western counties," that it is probably the eastern extension of the Encrinal band. Since in Ontario, Seneca, and Cayuga counties the most abundant coral faunas are in the Basal Hamilton, either this coral reef at Skaneateles Lake is (1) a continuation of the stratum called the "Basal Hamiton," which is several hundred feet above the Marcellus shales in the Cayuga Lake section, or (2) the Encrinal, or (3) the union of (1) and (2), or (4) a separate stratum. With the data now at hand Luther's supposition is as probable as any other.

Since the Encrinal is found in a number of localities between Lake Cayuga and Lake Erie, of the same lithological character, in relatively the same position in the shale, with a fauna which changes little in a distance of 125 miles, it should be considered as a continuous stratum. East of Cayuga Lake the correlation of the coral zones is yet to be worked out. However, conditions of sedimentation such as would produce a limestone stratum anywhere in the Middle Hamilton would be adapted to and contain what might be called a limestone fauna which would not differ materially from the fauna of the Encrinal; and whether this stratum were continuous or not, the same association of fossil would probably exist.

GASTEROPODA.

Gasteropoda predominate both in specific and in individual development in the lower shales of Ontario County. This is also the condition at Eighteenmile Creek, where only one gasteropod, *Platyostoma lineata*, is found above the Encrinal, and that but rarely in one layer. In the Cayuga Lake section Gasteropoda are not common in any portion of the section, but are about as frequently met with above as below the Encrinal. They occur, however, rather more frequently, in proportion to the Pelecypoda and Brachiopoda, in the fine shales of Zone C.

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[a] Report State Geol. New York, 1895.

USE OF TERMS "UPPER" AND "LOWER" HAMILTON FAUNA.

The data at hand—the faunules of the Cayuga Lake, Eighteenmile Creek, and Livonia sections—are sufficient to warrant some definite statement as to the propriety of the terms "an Upper Hamilton fauna" or "a Lower Hamilton fauna," used by some writers as signifying an ability to distinguish between them.

A comparison of the Cayuga Lake section with that of Eighteenmile Creek shows that the relative abundance of species and individuals in the Upper and Lower Hamilton of the two sections is reversed. At Cayuga Lake the number of species and individuals is greater above than below the Encrinal beds, while the opposite is decidedly true of the Eighteenmile Creek section.

Spirifer granulosus is a rather common fossil above and below the Encrinal at Cayuga Lake, but is restricted to the Lower Hamilton and the Encrinal at Eighteenmile Creek and to the Upper Hamilton at Livonia. *Reticularia fimbriata*, *Tropidoleptus carinatus*, and the lingulas are distributed in the three sections in the same manner as *Spirifer granulosus*.

Stropheodonta concava and *S. junia* are in the Lower Hamilton at Eighteenmile Creek, but are restricted to the Upper Hamilton at Cayuga Lake and Livonia.

Only two species of Brachiopoda have been found, which are restricted to the Upper Hamilton of the three sections, exclusive of the Encrinal — *Ambocœlia præumbona* and *Spirifer marcyi*. But it would not be remarkable if even these were found lower. Since these species have not been reported east of Cayuga Lake, they must of necessity have little use in stratigraphy. *Ambocœlia præumbona* has not been reported outside of New York State, and it may have originated in western New York after the Encrinal band was deposited.

Leiorhynchus limitare, *Spirifer macrus*, *Anoplotheca camilla*, and *Strophalosia truncata* are species which have not been reported above the Encrinal beds. The first is a typical Marcellus fossil (reported by Clarke[a] in a "recurrent fauna" above the "Basal limestone" in Ontario County); the second and third are typical Onondaga (Corniferous) species which have never been found above the Marcellus; only the fourth, *Strophalosia truncata*, is a species often found in the Hamilton. A comparison of the corals, pelecypods, and gasteropods brings the same results.

From the above it will be seen that the burden of evidence at present is against the supposition that it is possible, without the aid of stratigraphy, to distinguish between the Upper and Lower Hamilton fauna. However, the presence of *Spirifer marcyi* and *Ambocœlia præumbona* and the absence of *Strophalosia truncata* in a fauna would be presumptive evidence of the Upper Hamilton.

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[a] Rept. State Geol. New York, 1886.

EXPLANATION OF DIAGRAM, FIG. 8.

The data from which this diagram was constructed were obtained from the New York Geological Reports, commencing with vol. 4, 1867, Palæontology of New York, together with the Peabody Museum collections from Onondaga, Cayuga, Seneca, Genesee, and Erie counties used in the preparation of this paper. The distances are only approximate, some noted collecting locality being usually taken as a center.

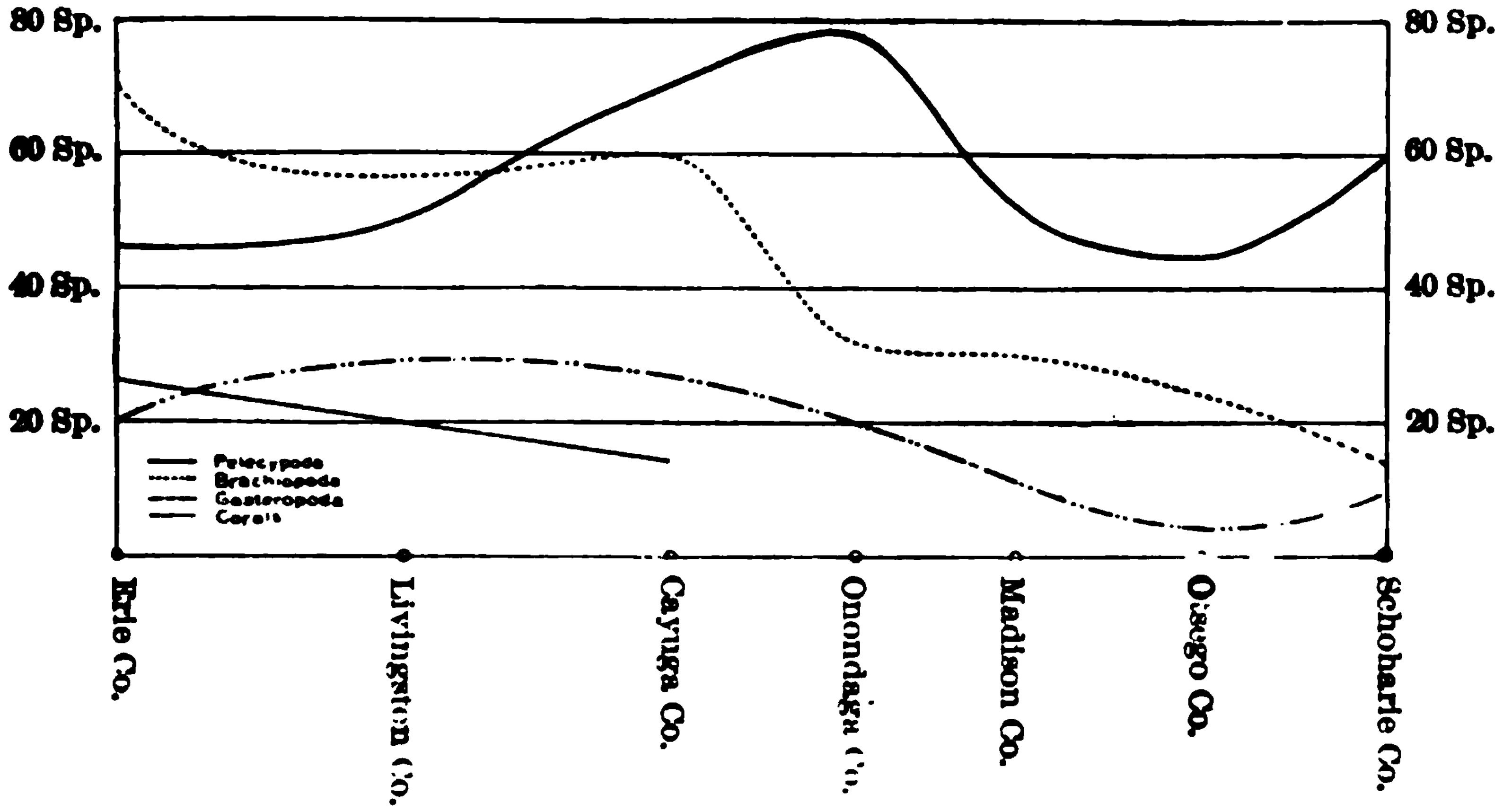

FIG. 8.—Diagram showing the distribution of fossils of the Hamilton stage throughout New York State.

The curves from Onondaga County west are probably more nearly correct than those east, because of the exceptionally careful collections from Pompey, Cayuga Lake, Livonia, and Eighteenmile Creek. The faunal lists of Prof. C. S. Prosser[a] make the collections from the extreme eastern portion of the State fairly full.

As is readily seen, the center of abundance of Pelecypoda is in Onondaga County. From that point the decrease to the west is rapid. The decrease in the number of species of Pelecypoda in the arenaceous shales east of Onondaga County would probably be less than represented were fuller collections to be had. That the conditions in eastern New York were much less favorable to the development of brachiopods than of pelecypods is shown by the fact that the relative abundance of brachiopods to pelecypods in Schoharie County is 13:60, while at Lake Erie the ratio is 70:40.

The increasing abundance of species of brachiopods from east to west is very striking and uniform. The line showing the abundance of Gasteropoda varies less from east to west than the other classes. The data concerning the corals show a uniform increase between Cayuga and Erie counties.

[a] Fifteenth Ann. Rept. State Geol. New York, 1895.

Two facts should be borne in mind in the consideration of the relative abundance of fossils when studied geographically, (1) the excellent opportunities for collecting in certain localities, as central and western New York, and the greater difficulty in others, as the eastern counties of New York, and (2) the fact that often in a formation the same time elapsed during the deposition of a few feet of sediment in one place that it took for the deposition of many times that thickness in another locality in the formation. The time required for the deposition of the 67 feet of sediment at Eighteenmile Creek, the 517 feet at Livonia, the 1,100 feet at Cayuga Lake, and the great thickness of the eastern shales was the same. At any one time there may not have been a greater number of living shells in Erie County than in the central or eastern part of the State; the conditions were, however, more favorable for the development of brachiopods and corals than for pelecypods.

The change from east to west, not only in the relative number of species but in the species themselves, is spoken of by Hall[a] as follows: "So great is this change that if a collection of fossils from the Hamilton formation in the counties of Albany and Schoharie be compared with a collection from the same group in Genesee and Erie counties the number of species common to both would be less than has been sometimes indicated as passing from one geological formation to another."

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[a] Preface to Pal. New York, vol. 4, 1867.

CHAPTER VI.

CONCLUSIONS.

In this investigation the following conclusions have been reached:

(1) There are a number of fossil faunules in the Hamilton formation which can be quite accurately defined. A glance at the diagrams Pl. V, *A* and *B*, and the table (Appendix) shows the distinctness with which many of these faunules are marked off. On the present sea bottom it is possible, given the conditions of bottom, depth, temperature, etc., in any region, to state with considerable certainty the composition of the faunule. The boundary line between modern faunules is sometimes distinct, but often there is such a mixture of the two faunules at the boundary that it is impossible to state where the line should be drawn. In the vertical distribution of fossil faunules the same difficulty is encountered. Shales containing a mixture of faunules are not uncommon, but where uniform conditions prevailed for a considerable length of time a definite group of species occurs. Occasionally the change was sudden, and the faunules are separated by a distinct line. Zone D is an excellent example of such a case; the shales above and below are almost barren of fossils, while Zone D is very fossiliferous. Occasionally a thin layer of fine shale is seen in the midst of a fossiliferous zone, or a thin layer rich in fossils in a barren zone.

(2) The difference between the composition of different faunules of the Hamilton formation is often more marked than between faunules of the same facies belonging to different formations. A study of living faunules leads one to expect such a condition, since in a short distance bathymetrically and geographically there is often a complete change in species.

(3) Migration of the organisms which lived during the Hamilton stage was undoubtedly accomplished in the same way as at present.[a] Such animals as Crustacea and *Orthoceratites* had considerable power of movement in the adult condition, but the common fossil animals, such as the brachiopods and pelecypods, were practically stationary when mature. The only means of migration for such classes was during the free swimming stage. During this stage they were carried about by currents and to some extent moved by their own activity.

[a] See Parker and Haswell, Text-Book of Zoology, and other Zoologies. Marine Bionomy Gralan

Zoologists cite many cases of the sudden appearance of species previously unknown to certain localities which were carried there during the free swimming stage by unusual conditions. These species often live but one year, and may not be seen again for years. Drifting timber and other means enable old and young of certain species to be carried long distances. The migration of the species making up the bulk of the Hamilton faunules undoubtedly took place, for the most part, during the free swimming stage.

(4) The repetition of faunas such as are found in a section like that of Cayuga Lake shows that there was an oscillation of similar conditions. It is probable that had the conditions remained uniform during the whole of the stage only one of these faunas would have occurred. The *Leiorhynchus* zone is several hundred feet thick in this region. There is no objection to the supposition that such a faunule would have lived on throughout the stage had the conditions remained as they were during the deposition of that zone.

(5) An "accidental" faunule is one which has been produced in a long period of time in a region where sedimentation has been very slight, but in which the conditions changed for short periods sufficiently to introduce a few species. In the aggregate the number of species of such a faunule may be great. A faunule of this character is very confusing, composed, as it is, of species from perhaps several faunules. It was not unusual for a thousand or more feet of sediment to be deposited in one region, while in another, during the same period of time, only a few feet were laid down. It is consequently unsafe to say, because fossils are abundant in a few inches of shale, that the conditions were necessarily exceptionally favorable for the development of that faunule. It is not impossible that hundreds or even thousands of years may have elapsed during the deposition of such a zone. The comparison of the thickness of the Hamilton formation at Cayuga Lake with that at Eighteenmile Creek showed that while 1,100 feet of shales were deposited in the Cayuga Lake region only 67 feet were deposited at Eighteenmile Creek. On the other hand, that great length of time and little sedimentation are not necessary for the formation of all fossiliferous zones is evident from the peculiar and characteristic faunules of these zones and the position of the fossils in the shale and limestone.

(6) In a section such as that of the Hamilton formation at Cayuga Lake, which represents in its formation between 1,846,150 and 26,153,840 years,[a] if the statement "natura non saltum facet" is granted, one should, with some confidence, expect to find many—at least some—evidences of evolution. A careful examination of the fossils of all the zones, from the lowest to the highest, failed to reveal any evolutional changes, with the possible exception of *Ambocœlia præumbona.*

[a] The first estimate is from Dana; the second is the maximum of Geikie. The Meso-Devonian was estimated as one-third the Devonian.

The species are as distinct or as variable in one portion of the section as in another. Species varied in shape, in size, and in surface markings, but these changes were not progressive. The conclusion must be that, so long as the conditions of sedimentation remain as uniform as they were in the section under consideration, the evolution of brachiopods, gastropods, and pelecypods either does not take place at all or takes place very seldom, and that it makes little difference how much time elapses so long as the conditions of environment remain unchanged.

(7) An analysis of the Hamilton faunas shows conclusively that there is little basis for the terms "an upper" and "a lower Hamiltonian fauna" ~~unless~~ these terms are used to signify that it is possible in isolated sections to state, from the composition of the fauna, whether the rock is above or below the Encrinal bed.

For "unless" in third line
from [illegible] when.

CHAPTER VII.

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APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York.*

[A = abundant. C = common. Cr = fairly common. r = rare. R = very rare.]

	Marcellus.		Lower Hamilton.									Encrinal bed.	Upper Hamilton.												
	Hamilton-Onondaga (Corniferous) zone.	First Leiorhynchus zone	Second Leiorhynchus zone.	First Terebratula zone (See text.)	Third Leiorhynchus zone.	Michelinia zone.	Chonetes vicinus zone.	(Transition zone.)	First Cypricardella-Athyris zone	Tellinopsis zone.	Second Cypricardella-Athyris zone.	Second Terebratula zone.	Orthonota zone.	(Transition zone.)	Chonetes zone.	First Ambocœlia zone.	Chonetes lepidus zone.	Second Ambocœlia zone	Strophodonta-Coralline zone	Modiella pygmæa zone.	Ambocœlia præumbona zone.	Orbiculoidea zone.	(Transition zone.)	Spirifer-Atrypa zone.	Cystodictya zone
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
ANTHOZOA-ACTINOZOA																									
1. Streptelasma rectum				r		R			r										A	R		Cr	Cr	C	R
2. Zaphrentis simplex																									R
3. Amplexus sp undet																				Cr			C	Cr	R
4. Heliophyllum halli				Cr																				R?	
5. H. confluens												R													
6. Diphyphyllum archiaci																									R
7. Favosites argus																									R
8. F. sp. (undet.)			R						R			r													R
9. Michelinia stylopora						Cr			R										R	R					
10. Trachypora ornata												r													R
11. Aulopora serpens			R						R?																R
12. Ceratopora dichotoma						r			R						R										
13. Syringopora sp				r																					
14. Chætetes fructicosa										R															R

APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York*—Continued.

	Marcellus.		Lower Hamilton.									Encrinal bed.	Upper Hamilton.												
	Hamilton-Onondaga (Corniferous) zone.	First Leiorhynchus zone.	Second Leiorhynchus zone	First Terebratula zone (See text.)	Third Leiorhynchus zone	Microdonella zone	Chonetes vicinus zone.	(Transition zone.)	First Cypricardella-Athyris zone	Tellinopsis zone.	Second Cypricardella-Athyris zone	Second Terebratula zone	Orthonota zone	(Transition zone.)	Chonetes zone.	First Ambocoelia zone.	Chonetes lepidus zone.	Second Ambocoelia zone	Stropheodonta-Coralline zone.	Modiella pygmæa zone	Ambocoelia præumbona zone	Orbiculoidea zone.	(Transition zone.)	Spirifer-Atrypa zone.	Cystodictya zone.
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
CRINOIDEA.																									
15. Granatocrinus leda												R													
16. Ancyrocrinus bulbosus												R													
17. Dichocrinus									R																
18. Crinoid stems and plates			RR	C	R	C			r	r		A	C	C	R	R		R	A	Cr			r	Cr	C
VERMES.																									
19. Spirorbis angulatus		R																							
BRYOZOA.																									
20. Hederella canadensis																									R
21. Reptaria stolonifera		R																							R
22. Tæniopora exigua																									Cr
23. Cystodictya incisurata																			Cr					C	A
24. Polypora multiplex																			r						
25. Bryozoa, undet				Cr	R	R			R	r	r	C	Cr	C	R			R	C	R				C	AA
BRACHIOPODA.																									
26. Lingula delia						R?		R	R?					R?	R					R		Cr		R	R
27. L. densa															R?					R					
28. L. ligea									R															R	R
29. Dignomia alveata													B												

30. Camarotœchia congregata				R					R					r											R
31. C. dotis												r?													
32. C. horsfordi												R													R
33. C. prolifica						r?						r?							r					R?	R
34. C. sappho				R			R					R												R	R
35. Hypothyris cuboides																									r
36. Leiorhynchus laura	Cr?		C	R	C	R			R							R				R	R	A	CA	C	
37. L. limitare		C																							
38. Centronella impressa												C													
39. Cryptonella planirostris				r																					
40. C. rectirostris				Cr																					
41. Eunella lincklæni				Cr								Cr												r	Cr
42. Tropidoleptus carinatus	R		R	Cr	r	C	Cr	C	CA	R	Cr	C	CA	CA	C	r		r	R	Cr	R			R	CA
43. Atrypa reticularis				R					R		Cr								C	R		r	r	A	Cr
44. Cyrtina hamiltonensis				Cr															R	R					R
45. Spirifer audaculus				Cr					R		Cr	R		Cr	R				r	Cr		R	CA	A	CA
46. S. audaculus macronotus				r					r		r	R							Cr	Cr				r	
47. S. divaricatus				R								r													
48. S. granulosus				R		R			Cr		Cr	Cr			r				r	Cr				C	R
49. S. marcyi																								C	Cr
50. S. pennatus			R	r		Cr	C	C	A	Cr	C	C	r	A	C			Cr	r	Cr	C	R	Cr	Cr	C
51. S. tullius									R			Cr			R					r	Cr	Cr			
52. S. macrus	C																								
53. Delthyris consobrina				R					R						R			Cr	Cr	R				R	
54. D. sculptilis				r																					
55. Martinia subumbona																				R					
56. Ambocœlia præumbona																				R	C	Cr			
57. A. umbonata	Cr	Cr	Cr	C	Cr	r			R	C	R		Cr	R	Cr	A	C	AA	R	C	C	Cr		B	R
58. Reticularia fimbriata				Cr					r			R		C					r			R	R	r	Cr
59. Nucleospira concinna				r								Cr							Cr						R
60. Anoplotheca camilla	Cr																								
61. Vitulina pustulosa				Cr								Cr													
62. Athyris spiriferoides	CA			Cr		R			CA	R	CA	r		r	C	Cr		C	Cr	Cr		r	A	A	Cr
63. Meristella haskinsi				R								R													
64. Orbiculoidea doris			R			R														R					

APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York*—Continued.

	Marcellus		Lower Hamilton									Encrinal bed	Upper Hamilton												
	Hamilton-Onondaga (Corniferous zone)	First Leiorhynchus zone	Second Leiorhynchus zone	First Terebratula zone (See text)	Third Leiorhynchus zone	Michelinia zone	Chonetes vicinus zone	(Transition zone)	First Cypricardella-Athyris zone	Tellinopsis zone	Second Cypricardella-Athyris zone	Second Terebratula zone	Orthonota zone	(Transition zone)	Chonetes zone	First Ambocœlia zone	Chonetes lepidus zone	Second Ambocœlia zone	Stropheodonta-Coralline zone	Modiella pygmæa zone	Ambocœlia præum (?) zone	Orbiculoidea zone	(Transition zone)	Spirifer-Atrypa zone	Cystodictya zone
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
BRACHIOPODA—continued.																									
65. Orbiculoidea hamilis										R															
66. O. lodiensis																				R					
67. O. lodiensis media			R	R						R?					R	Cr		R		R		A	R		
68. Craniella hamiltoniæ				R								R							R	R			R	R	Cr
69. Pholidops hamiltoniæ									Cr						Cr	C	R	CA	r	C	C		CA	R	
70. P. oblata												**R**													
71. Stropheodonta concava																			Cr					Cr	R
72. S. demissa									R																
73. S. inæquistriata				R					r			Cr							C					r	C
74. S. junia														r								R	r	Cr	Cr
75. S. perplana	R			C		R		R	Cr		Cr	C		R	R		R	r	Cr			r	C	Cr	r
76. S. perplana var																							R		
77. Pholidostrophia iowaensis									C	R				R											R
78. Orthothetes chemungensis arctistriatus	R			Cr		R			Cr			Cr	R	R	R				R	R				R	R
79. O. chemungensis perversus				Cr							R														
80. O. chemungensis var	Cr																								
81. Chonetes coronatus	R			Cr				C	r	R	Cr	Cr		Cr	Cr				C	r				R	R

82. C lepidus			B	R	r						r			r	r	A	Cr	Cr	r	r	R	R	Cr	r
83. C lineatus	C																							
84. C. mucronatus	CA	C	r	CA							r	r	r	A	C	R	C	r	C	r	R	A	Cr	r
85. C. scitulus		r	R							A		r		A		r	r	Cr	Cr		r		R	R
86. C setigerus																			R					
87. C. vicinus				R		r	A	A	CA		Cr													
87a C. sp																								
88. Productella spinulicosta		R	R	Cr		Cr			r	r	r	R		R				R	R			R	r	r
89. P navicella			R																					
90. Strophalosia truncata		C	r		R	r				R									R?					
91 Rhipidomella vanuxemi									R?		R	C		R			Cr	CA	C	R	R	A	Cr	Cr
92. R cyclas																			R					
93. R. penelope																								R
93a. Pentamerella pavilionensis				R																				
PELECYPODA																								
94 Phthonia nodicostata													Cr											
95. P. cylindrica																		R						R
96. P. sectifrons																								R
97. Orthonota carinata									R		R							R	R					
98. O undulata										Cr	R		C										R	
99. O. parvula				R				Cr	R					R	R			R	r	R		R	R	
100 Prothyris lanceolata											r		Cr							R			R	R
101. P truncata																							r	R
102. Grammysia constricta							R	r		R			R	R					R				R	
103. G cuneata				Cr?					R	Cr				r			R		R					
104 G arcuata				Cr		R	r	R	R	R	Cr		r	R					R					R
105. G bisulcata							r																	
106. Elymella fabalis																								R
107. E. nuculoides																							R	
108. Glossites subtenuis																							R	
109. Tellinopsis subemarginata			R	Cr		r	C		R	CA	r		Cr		R		R	R	r	R	R	R	Cr	
110 Panenka linckleni																			R?					
111. P potens			R?																R?					
112 P sp.																							R	

APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York*—Continued.

	Marcellus.		Lower Hamilton.									Encrinal bed.	Upper Hamilton												
	Hamilton-Onondaga (Corniferous) zone	First Leiorhynchus zone	Second Leiorhynchus zone.	First Terebratula zone. (See text.)	Third Leiorhynchus zone	Michelinia zone.	Chonetes vicinus zone.	(Transition zone.)	First Cypricardella-Athyris zone	Tellinopsis zone	Second Cypricardella-Athyris zone.	Second Terebratula zone	Orthonota zone.	(Transition zone.)	Chonetes zone.	First Ambocoelia zone.	Chonetes lepidus zone.	Second Ambocoelia zone.	Stropheodonta-Coralline zone.	Modiella pygmaea zone	Ambocoelia praeumbona zone.	Orbiculoidea zone.	(Transition zone.)	Spirifer-Atrypa zone.	Cystodictya zone.
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
PELECYPODA—continued																									
113. Glyptocardia speciosa			R		Cr	r			R									R		R		R			
114. Nuculites triqueter.		C	Cr		R	Cr		R	Cr	C	Cr				r			R	r	Cr	R	r	Cr	r	R
115. N. oblongatus			R	R	R	R	R		R	C	R		r		R				r	Cr		r	C	Cr	R
116. Nucula varicosa					R	R		R			R									r	r	R	R		
117. N. randalli									R?																
118. N. lirata			R			R			R	r					R				r	Cr	R		R	r	
119. N. bellistriata							R	R	r	C	Cr				R?					Cr	Cr			R	
120. N. corbuliformis		r	R	R	C	Cr		Cr		r	Cr			R	Cr	r	R	Cr	R	C		Cr	R	R	R
121. Leda rostellata									R	r	R								Cr	R	R			R	
122. L. brevirostris																									R
123. Palaeoneilo constricta			[illegible]	Cr		R	Cr	C	Cr	R	Cr		Cr	r	C	r	Cr	C	r	C	C	R	C	C	r
124. P. emarginata									Cr			R		R						Cr	r	r	Cr	r	R
125. P. plana																		R	R	Cr			C	R	
126. P. maxima																									R
127. P. muta																R?		R	R	r				r	
128. P. fecunda									R									R		R				R	
129. P. tenuistriata																						R	Cr	r	

130. Parallelodon hamiltoniæ			Cr		R		R	r		R	R			R			C	r	r			Cr	Cr	R
131. Sphenotus arcæformis										R														
132. S. cuneatus						r	R																	
133. S. solenoides			R								R													
134. Pterinea flabella			R		r		R?	Cr																
135. Lunulicardium fragile	R	Cr	r	Cr	R	r										R			R				R	
136. L. curtum	R	R	R	R																				
137. L. ornatum		R																						
138. Plethomytilus oviformis			R		R																		R	R
139. Mytilarca gibbosa													R?											R?
140. Spathe[redacted] typica																							[redacted]	
141. Conocardium normale										R														
142. Actinopteria boydi			Cr					R											R				R	r
143. A. decussata											R								R				R	
144. A. subdecussata																			R					
145. Leiopteria greeni											R													
146. L. lævis	C	R	r	R	Cr	R		r											Cr	Cr?	r		?	
147. L. rafinesquii			R						r?															
148. L. gabbi		R																	R?					
149. L. sayi							R	R?						R			R?		Cr					
150. L. conradi			R																R					
151. L. dekayi																			R					
152. Modiella pygmæa		R	r	C	Cr			r	Cr					r	R	R	r	R	CA	r	Cr	C	Cr	
153. Schizodus appressus			R					R			r						R			R?			R	
154. S. contractus			R																					R
155. Aviculopecten princeps			Cr	R	R			Cr	R		R	R	r?										Cr	Cr
156. A. fasciculatus			R?																					
157. A. scabridus					R																			
158. Pterineopecten undosus								R		R									R?	R	R		R	R
159. P. vertumnus								R	R?															R
160. P. intermedius			r		R				R					R			R	R	R					R
161. P. hermes														R				r				R		r
162. Lyriopecten orbiculatus			R																					
163. Modiomorpha subalata			r		Cr				Cr										r		R		R	
164. M. concentrica			R				C	Cr		R	R			Cr			r	Cr	?			C	Cr	R

APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York*—Continued.

	Marcellus.		Lower Hamilton.									Encrinal bed.	Upper Hamilton.												
	Hamilton-Onondaga (Corniferous) zone.	First Leiorhynchus zone	Second Leiorhynchus zone	First Terebratula zone (See text)	Third Leiorhynchus zone	Michelinia zone	Chonetes vicinus zone.	(Transition zone.)	First Cypricardella-Athyris zone	Tellinopsis zone	Second Cypricardella-Athyris zone	Second Terebratula zone.	Orthonota zone	(Transition zone.)	Chonetes zone.	First Ambocœlia zone	Chonetes lepidus zone	Second Ambocœlia zone	Stropheodonta-Coralline zone	Modiella pygmæa zone	Ambocœlia præumbona zone	Orbiculoides zone	(Transition zone.)	Spirifer-Atrypa zone.	Cystodictya zone.
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
PELECYPODA—continued.																									
165. Modiomorpha mytiloides				r		r		R	r			R			Cr								r	r	
166. M. alta																								R	
167. Goniophora hamiltonensis				r					R?		R		R					R	R	R					R
168. G. truncata																			R					R	
169. G. rugosa								R	R										R?	R				R	
170. G. glaucus																								R?	
171. Pholadella radiata				R		r		Cr	r	Cr				R	C		R	R		r		R			
172. P. parallela																				R					
173. Cimitaria corrugata									R															R	
174. C. elongata												R													
175. Cypricardella bellistriata				r		Cr	Cr	CA	CA		Cr	r			R					r			C	C	Cr
176. Cypricardinia indenta				Cr					R										R	R			r	C	R
177. Paracyclas tenuis				R				R	r	R	Cr				R	R	r	Cr		R	R		Cr	R	
178. P. lirata																				R					
GASTEROPODA																									
179. Pleurotomaria itys		r							R	R					R					r			r	R	R
180. P. capillaria				R		R												R		r	r	R			

181. P trilix														R							R			R	R
182. P sulcomarginata		Cr																		R			R		
183. P rotalia			R																	R?					
184. P. rugulata		Cr	r		Cr	r			R																
185. Bellerophon patulus			R	R		R				R	R			Cr											r
186. B. leda			Cr	R	r	R		R	R	C			r	Cr	R					R			R	r	
187. B. lyra															R										
188. B crenistria			R						R			R	R							R				R	
189. Cyrtolites mitella									r	Cr										R					
190. Euomphalus sp															R										
191. Platyceras conicum												R													
192. P. erectum					R							R		Cr					R	R				R	r
193. P. bucculentum																			R					R	
194. P. carinatum																							R	R	
195. Platyostoma lineata														R					R	R					Cr
196. P varians										R															
197. Loxonema hamiltoniae	R?	R	r			R			R			R	Cr		R					R				r	
198. L delphicola				r?					r?			R			R			R		r		R	Cr	Cr	
199. Callonema imitator														R											
200. Styliola fissurella	C	C	C		C	R														R					
201. Tentaculites bellulus	C									R		R?								R				R	
202. Coleolus tenuicinctum				r		R			R		R				R		R			R			R		
203. Hyolithes aclis				r	R	R			Cr						R				R	R			R		
204. H striatus																				R	R?			R	
205. Conularia undulata				R					R																
CEPHALOPODA																									
206. Orthoceras crotalum			R?	r	r?				R						R				R	R	R	R	R	R	R
207. O. calamen																				R?			R	R	
208. O nuntium																				R				R	
209. O. subulatum		C?									R?									Cr				r	
210. O constrictum						R	R																		
211. O. exile									R?											R			R	R	
212. O marcellense																									
213. O. sp. undet		Cr	Cr	r	C	C	R			R			r	r	R	R	R	R		C		R			
214. Nautilus liratus juvenis				R																					

APPENDIX.—*Table showing vertical distribution of faunal zones, with their contained faunules, in the Hamilton formation of Cayuga Lake, New York*—Continued.

	Marcellus		Lower Hamilton.									Encrinal bed	Upper Hamilton.												
	Hamilton-Onondaga (Corniferous) zone	First Leiorhynchus zone	Second Leiorhynchus zone.	First Terebratula zone. (See text)	Third Leiorhynchus zone.	Michelinia zone	Chonetes vicinus zone.	(Transition zone)	First Cypricardella-Athyris zone	Tellinopsis zone.	Second Cypricardella-Athyris zone.	Second Terebratula zone.	Orthonota zone.	(Transition zone.)	Chonetes zone.	First Ambocœlia zone	Chonetes lepidus zone	Second Ambocœlia zone	Stropheodonta-Coralline zone.	Modiella pygmæa zone.	Ambocœlia præumbona zone	Orbiculoides zone.	(Transition zone.)	Spirifer-Atrypa zone.	Cystodictya zone.
	A	B	C	D	F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
CEPHALAPODA—continued																									
215. Nautilus fragments		R	R	Cr	R	r	r		Cr	Cr	r					R	R			r					
216. Gomphoceras sp. undet.		R																		C		R			
217. Goniatites discoideus					Cr				R											Cr		R	R	r	
218. G. uniangularis			R						R											R					
CRUSTACEA																									
219. Proetus rowi												R?													
220. P. microgemma																									R?
221. P. macrocephalus												R													R
222. Homalonotus dekayi				R								Cr													
223. Phacops rana		R	R	Cr	R	R		R	r		R	C		C	Cr	CA	C	A	C	C		R	C	C	r
224. P. cristata var. pipa	R																								
225. Dalmanites boothi			R	C		R	R		R		R	r	r	Cr	Cr	r	Cr	r	Cr	Cr	Cr	R	Cr	Cr	R
226. D. boothi calliteles																							R		r
227. Echinocaris punctata						R			R		R														R
228. Tropidocaris hamiltoniæ															R										

229. Rhinocaris sp.																										
230. Mesothyra oceani		R	R																							R
231. Ostracods sp. undet		Cr	Cr		C	r	R		C					R						r		R	R	R		
PLANTÆ.																										
232. Lepidodendron gaspianum			R																							
233. Plant fragments			R	R	R	R	r	r	R							R	R		R		Cr				R	CA
234. Taonurus									C	C	R														A	

INDEX.

Names in italic are synonyms; figures in black-face type are numbers of pages containing description or classification.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 206.]

The serial publications of the United States Geological Survey consist of (1) Annual **Reports**, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Bulletins, Professional Papers, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, Methods of hydrographic investigation; N, Water power; O, Underground waters; P, Hydrographic progress reports. This bulletin is the sixtieth in Series C, the complete list of which follows (all are bulletins thus far):

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE ACTION OF AMMONIUM CHLORIDE UPON SILICATES

BY

FRANK WIGGLESWORTH CLARKE

AND

GEORGE STEIGER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1902

CONTENTS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., September 26, 1902.

SIR: I have the honor to transmit herewith a memoir by Messrs. Clarke and Steiger on the action of ammonium chloride upon silicates, with the recommendation that it be published as a bulletin. These researches are of great geological importance for the light they throw upon the rational constitution of minerals. They are based on a method which is wholly novel and which is capable of wide application. The work is most creditable to the authors and to the United States Geological Survey.

Very respectfully, your obedient servant,

GEORGE F. BECKER,
Geologist in Charge,
Division of Chemical and Physical Research.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE ACTION OF AMMONIUM CHLORIDE UPON SILICATES.

By Frank Wigglesworth Clarke and George Steiger.

INTRODUCTORY STATEMENT.

In a series of investigations by Clarke and Schneider, which were carried out in the laboratory of the United States Geological Survey between the years 1889 and 1892,[a] a number of reactions were studied which shed some light upon the constitution of the natural silicates. Among these reactions two were of peculiar interest, on account of their simplicity and the ease with which they could be applied.

First, in the case of talc, it was found that one-fourth of the silica could be liberated by ignition; and that the fraction thus set free was measurable by solution in aqueous sodium carbonate. This reaction suggests that other acid metasilicates may behave in a similar way, and that we perhaps have a means of discrimination between such salts and other compounds which simulate them. In other words, an acid metasilicate may be experimentally distinguished from a pseudo-metasilicate by the way in which it splits up when ignited. Evidence bearing upon this supposition will be found in the present paper.

The second of the reactions just referred to is that between dry ammonium chloride, at its temperature of dissociation, and various silicates, different minerals being very differently attacked. Some are completely decomposed, others are affected but slightly, and in certain cases substitutions are produced of a most suggestive character. To a certain extent, the two reactions overlap; that is, each one bears somewhat upon the other, and hence both have received consideration in the present series of researches.

In the earlier stages of our work the several silicates which were studied were heated with dry ammonium chloride in open platinum crucibles. The temperature chosen was 350°, at which point the chloride breaks up into gaseous hydrochloric acid and free ammonia,

[a] Bulls. U. S. Geol. Survey No. 78, p. 11; No. 90, p. 11; No. 113, pp. 27, 34.

and in this way partial changes were effected. Later, the heatings were performed in sealed combustion tubes, and then the reaction proved to be much more far-reaching. In nearly every case the material taken for investigation was ground up into one large, uniform sample, upon which all the experiments were performed, and in that way the results obtained are comparable with one another. The few exceptions to this rule of procedure will be noticed at the proper places. In testing for soluble silica, a standard solution of sodium carbonate, containing 250 grams to the liter, was used, and here again the experimental conditions have been kept uniform. So much premised, we may proceed to the description of our investigations, species by species, in detail.

ANALCITE.

Analcite, from many points of view, is a species of peculiar interest, and of late years it has received a great deal of attention. Its formula may be written in various ways, especially as regards the interpretation of its one molecule of water; but evidence too often has yielded before preconceived opinion. Additional evidence is now available, partly from the experiments of Friedel, and partly from the data obtained during the present investigation.

The analcite first examined by us was in well-developed crystals from Wassons Bluff in Nova Scotia. A uniform sample was prepared, as usual, and the analysis, given below, is contrasted with the theoretical composition required by the accepted empirical formula $NaAlSi_2O_6 . H_2O$.

	Found.	Calculated.
SiO_2	57.06	54.55
Al_2O_3	21.48	23.18
Fe_2O_3	.13	
CaO	.16	
Na_2O	12.20	14.09
H_2O at 100°	.58	
H_2O over 100°	8.38	8.18
	99.99	100.00

Fractions of water.

At 100°	0.58
At 180°	1.16
At 260°	3.64
At 300°	1.57
Low redness	1.90
Full redness	.11
Blast	none
	8.96

The fractional water determinations were made by heating in an air bath to constant weight at each temperature up to 300°, and finally over the direct flame. The first fraction, at 100°, is evidently hygroscopic or extraneous water, which can be disregarded. The remainder of the water, 8.38 per cent, belongs to the species. The significance of the analytical figures will be considered later.

Upon boiling the powdered analcite with the standard sodium carbonate solution, 0.73 per cent of silica was extracted. After ignition the mineral in two determinations yielded 1.46 and 1.38 per cent, respectively. The splitting off of silica is, therefore, very slight; and one of the formulæ proposed by Doelter,[a] $Na_2Al_2Si_2O_8+2H_2SiO_3$, may be set aside as improbable. Metasilicic acid, or an acid metasilicate, can hardly be present in analcite; although the possibility of a neutral metasilicate, as indicated by the empirical formula, is not excluded. If Doelter's formula were correct, one-half of the silica should be liberated by ignition.

Upon heating analcite with dry ammonium chloride, notable results were obtained even in an open platinum crucible. Sodium chloride was formed, which could be leached out by water and measured, while ammonia, free from chlorine, was retained by the residue to a notable and surprisingly stable degree. The experiments in detail were as follows:

A. Analcite, mixed with four times its weight of ammonium chloride, was heated for four hours to 350°. There was a gain in weight of 2.18 per cent, and 6.10 per cent of soda, or one-half of the total amount, was converted into NaCl, which was leached out by water, examined as to its purity, and weighed. In the residue 1.20 per cent of silica was extracted by sodium carbonate, showing that no more splitting off had occurred than was previously observed. The gain in weight, as will be seen from subsequent experiments, is due to the fact that all of the NH_4Cl had not been driven off, or else that more water was retained.

B. Analcite was ground up with four times its weight of NH_4Cl, heated for several hours, reground with another fourfold portion of chloride, and heated to 350° for twenty-one hours. Gain in weight, 0.08 per cent. 5.57 per cent of soda was extracted as chloride.

C. Analcite heated to 350 for eight hours with four times its weight of NH_4Cl. Loss of weight, 0.10 per cent.

D. Six grams of mineral and 28 of chloride, mixed by thorough grinding, were heated to 350° for fourteen hours; then were reground with 28 grams of fresh NH_4Cl and heated for thirty-five hours. Loss of weight, 0.13 per cent. 5.07 per cent of soda was extracted as chloride, plus 0.14 of ammonium chloride unexpelled. 2.03 per cent of silica was rendered soluble in sodium carbonate.

So far three facts are noticeable. First, the weight of the mineral after treatment is almost exactly the same as before, showing that gains and losses have balanced each other. Secondly, little silica has been split off. Thirdly, approximately, but not rigorously, one-half of the soda has been converted into NaCl. In A it was exactly half; in the other experiments, a little less than half. Furthermore, in the sodium chloride dissolved out, there is only a very little ammonium

[a] Neues Jahrbuch, 1890, Vol. I, p. 133.

chloride, amounting at most to 0.14 per cent, calculated upon the weight of the original mineral.

In the residue of the analcite after extraction of sodium chloride, abundant ammonia can be detected, with either no chlorine or at most a doubtful trace. If, however, the unleached mineral, still retaining its sodium chloride, be heated strongly, say, from 400° up to redness, NH_4Cl is regenerated and given off. Its absence, as such, both from the leach and the residue was repeatedly proved. The ammonia and water retained by the analcite after heating to 350° with ammonium chloride were several times determined, and the following percentages, still reckoned on the original mineral, were found:

	NH_3.	H_2O.
In B	2.03	2.25
In C	2.19	2.00
In D	2.36	1.89
"	2.35	
"	2.06	
Mean	2.20	2.04

Correcting the ammonia for the 0.14 of NH_4Cl found in D, the mean value becomes 2.15. The determinations of it were made by three distinct methods, and there is no possible doubt as to its presence.

The composition of the analcite after the treatment with ammonium chloride may now be considered, with the subjoined combination of the data. The NaCl in A, 11.50 per cent, was in material which had gained 2.18 per cent, and is subject to a correction which reduces the figure to 11.26. In B, C, and D the corresponding correction is so small that it may be neglected. The last column gives the composition of the leached residue, recalculated to 100 per cent, after deduction of NaCl and the soluble silica. The letters refer back to the several experiments, and the little iron is included with the alumina.

	A.	B.	C.	D.	Average.	Residue.
Sol. SiO_2	1.20			2.03	1.61	
Insol. SiO_2				54.96	54.96	62.59
Al_2O_3				21.37	21.37	24.34
CaO				.16	.16	.18
NaCl	11.26	10.50		9.57	10.44	
Na_2O				7.12	7.12	8.11
NH_3		2.03	2.19	2.21	2.15	2.46
H_2O		2.25	2.00	1.89	2.04	2.32
				99.31	99.85	100.00

The results thus obtained with analcite from Nova Scotia were so remarkable that further investigation seemed to be needed upon material of different origin, and with variation in the details of manipulation. The new experiments, which have led to highly interesting consequences, are now to be described.

To the kindness of President Regis Chauvenet, of the State School of Mines, we are indebted for a liberal supply of well-crystallized analcite from North Table Mountain, near Golden, Colo., of which a uniform sample of about 80 grams was prepared. An analysis of the mineral gave the following results:

SiO_2	55.72
Al_2O_3	23.06
CaO	.17
Na_2O	12.46
H_2O at 100°	0.13
H_2O above 100°	8.26
	99.80

Water by fractions.

At 100°	0.13
At 180°	.75
At 260°	2.44
At 300°	1.28
At 350°	1.76
At redness	2.03
	8.39

Above a low red heat no further loss of weight was observed. Upon boiling the powdered mineral for fifteen minutes with the standard solution of sodium carbonate, 0.45 per cent of silica was dissolved. After ignition, 0.57 per cent was soluble, which is practically the same amount. No silica was split off by heating. The experiments with ammonium chloride fall into two series. The first of these was conducted precisely as in the case of the Nova Scotian material, namely, by grinding the powdered mineral into an intimate mixture with four times its weight of the chloride, and heating in an open crucible. In three cases the material, after volatilization of the ammonium chloride, was reground with a fresh amount of the salt, and then heated again. The temperature and duration of the experiments were purposely somewhat varied. After heating, the material was leached out with water, the sodium chloride which had been formed was estimated, and in the residue the fixed ammonia was determined.

In this series there were four experiments, with results as follows:

	Hours heated.	Temperature.	Soda removed.	Ammonia in residue.
A	28	300	4.75	2.04
B	84	350	6.36	2.88
C	26	350	3.76	1.72
D	5	340–380	6.70	2.85

In the analcite from Nova Scotia the ammonia retained by the leached residue ranged from 2.03 to 2.36 per cent, while the extracted soda varied from 5.07 to 6.10. In two of the new experiments these figures are perceptibly exceeded, and they represent the shortest duration of heating. Prolonged heating seems to be undesirable, and seems to undo a part of the reaction which has taken place; otherwise the results obtained are of the same order as their predecessors. About one-half of the soda in the analcite is converted into chloride, while variable ammonia is retained.

In the second series of experiments a sealed tube was substituted for the open crucible. The powdered analcite was intimately ground with four times its weight of ammonium chloride, as before, and then heated to 350° in a tube furnace for from four to eleven hours. Under these conditions practically the whole of the soda in the mineral was converted into sodium chloride, while all of the liberated ammonia was absorbed by the residual silicate. Upon leaching the contents of the tube with water, to remove sodium and ammonium chlorides, a residue was obtained which exhibited constant composition whether dried at 100° or at the ordinary temperature of the air. Three samples of the residue were prepared and analyzed; other samples were partially examined and used for subsidiary experiments. The three analyses, lettered for future reference, were as follows, the analcite itself being included in the table for comparison:

	Analcite.	Residue A.	Residue B.	Residue C.
SiO_2	55.72	61.93	61.68	61.79
Al_2O_3	23.06	25.21	25.33	25.24
CaO	.17			
Na_2O	12.46	.40	.22	.28
NH_3		7.23	6.95	7.71
H_2O	8.39	4.50	4.91	5.01
	99.80	99.27	99.09	100.03

Residue C was prepared with the greatest care, and was air dried. Exposed over sulphuric acid in a vacuum desiccator for fourteen days, it lost in weight only 0.08 per cent. Tested for chlorine, only a slight trace could be recognized, but upon boiling for fifteen minutes with sodium carbonate solution it yielded 1.97 of soluble silica. After ignition only 1.70 of silica was soluble, or somewhat less than before. Upon heating to constant weight at 300°, only 0.46 per cent was lost, but at 350° it slowly decomposed, giving off ammonia. At 300° the compound is stable.

The 0.28 per cent of soda remaining in residue C may be regarded as representing unaltered analcite, doubtless coarser particles which

escaped complete transformation. It corresponds to 1.98 per cent of analcite, which, together with the 1.97 of soluble silica and the 0.46 of water lost below 300°, may be deducted from the substance in order to obtain the composition of the definite compound. The latter amounts to 94.72 per cent of the total residue, and agrees very nearly in composition with the formula

$$2NH_3.H_2O.Al_2O_3.4SiO_2.$$

Recalculating the 94.72 of residue to 100 per cent, we get the following comparison between analysis and theory:

	Found.	Calculated.
SiO_2	61.07	60.92
Al_2O_3	26.15	25.88
NH_3	8.14	8.63
H_2O	4.64	4.57
	100.00	100.00

Written in rational form the compound becomes equivalent to an anhydrous ammonium analcite,

$$NH_4AlSi_2O_6;$$

that is, analcite in which sodium has been replaced by ammonium. From this point of view the reaction between analcite and ammonium chloride becomes a simple case of double decomposition, and is perfectly intelligible. To establish this conclusion, however, corroborative experiments were necessary.

In the first place, the observed equivalency between the sodium lost and the ammonia gained might be due to a mere coincidence, and so far be illusory. One atom of sodium, taking chlorine from ammonium chloride, liberates one molecule of ammonia, the amount which the analcite residue has retained. Suppose more ammonia were present; could it be absorbed?

To answer this question another tube was prepared, with the usual mixture of analcite and ammonium chloride. This was covered by a loose plug of glass wool, in front of which we placed enough pure lime to liberate about double the normal amount of ammonia. The tube was then sealed, and heated to 350°, as in the previous experiments. Upon opening the tube, a strong outrush of ammonia was noticed; but in the leached and thoroughly washed residue, only 7.52 per cent of ammonia was found. This quantity agrees with that from the previous samples, and shows that the limit of the reaction has been practically reached. One molecule of ammonia is retained, and no more.

Still another experiment was tried upon a portion of the residue marked C. If the compound is really an ammonium salt, it should

be decomposable by caustic soda in such a way as to reverse the reaction by which it had been obtained. The substance, however, is very insoluble, so that the reaction takes place slowly. To phenol phthalein it is absolutely neutral, and with Nessler's reagent it reacts only after long standing.

To settle the question a weighed portion of the compound was boiled in a distilling flask with a 10 per cent solution of sodium hydroxide, to which water was added from time to time. The distillate was collected in a tube containing aqueous hydrochloric acid; and the ammonia which passed over was weighed, ultimately as chloroplatinate. By four hours' boiling 6.90 per cent of ammonium was driven off and determined; and the residue remaining in the flask, after washing until no alkaline reaction could be detected in the wash-water, was examined for soda, of which 10.41 per cent was found. The anticipated reaction had taken place, although not completely; it was enough, however, to confirm our opinion, and to establish the nature of the new compound beyond reasonable doubt. Other confirmation was obtained later, from the study of leucite.

The foregoing paragraphs now enable us to understand a phenomenon which we observed in our work with the open crucible. In that case a partial reaction takes place between the analcite and the ammonium chloride, producing, as in the sealed tube, a mixture of an ammonium alumino-silicate with sodium chloride: the two substances being separable by leaching. But if, instead of leaching, the mixture be heated to full redness, ammonium chloride is re-formed and given off, leaving a residue which contains little or no sodium chloride, and is wholly insoluble, or almost so, in water. That is, the reaction which occurs at 350° is reversed at the higher temerature, and anhydrous analcite, or an isomer of it, is regenerated. Ammonium and sodium again change places, and the original state of molecular equilibrium is restored.

What, now, is the nature of the product obtained in the open crucible after sodium chloride has been removed? Is it a definite intermediate compound or an indeterminate mixture? At first we were inclined to accept the first of these alternatives, and we assigned to the substance the formula $H_2Na_2Al_4Si_8O_{24}.NH_3$, in which the ammonia plays a part equivalent to that of water. In this expression we were influenced by the researches of Friedel,[a] who had shown that ammonia could in part replace the "zeolitic" water of analcite; but it now appears that the phenomenon observed by him is quite distinct from that discovered by us, and is, indeed, of an entirely different order. We may, therefore, in accordance with our new data, rearrange the formula, transforming it to that of an ammonium salt, $HNa_2NH_4Al_4Si_8O_{24}$, the agreement with the analytical figures being approximate only. The results obtained are not sharp enough for certainty.

This product we are now inclined to regard as a mixture, although

[a] Bull. Soc. min. France, Vol. XIX, p. 94, 1896.

it is not strictly intermediate between analcite and its final ammonium derivative. Only half of the eliminated sodium has been replaced by ammonium, while hydrogen, or water, makes up the deficiency. It seems probable that the reaction in the sealed tube and that in the open crucible are at first essentially the same, but that in the latter case secondary reactions follow, which cause the variations in the final results. In the sealed tube the element of pressure comes into play, and the reaction is complete. In the open crucible pressure is lacking; some ammonia escapes fixation and reacts upon a part of the sodium chloride which was at first formed; hence the composition of the leached residue is essentially modified. This residue may be a definite compound, but the case in its favor is unproved and the presumption is rather against it.

The most remarkable fact developed by the foregoing experiments is the easy replaceability of the soda in analcite. This replaceability, however, is not limited to the substitution of ammonium for sodium; it appears to extend to other bases as well, and this we have proved in the case of silver. This is illustrated by three experiments upon the Colorado analcite, as follows:

A. Analcite, intimately mixed with dry silver nitrate, was heated in a sealed tube to 400° for four hours.

B. Analcite and silver nitrate were heated in a sealed tube to 250° for four hours.

C. Ammonium analcite, mixed with dry silver nitrate, was heated in a sealed tube to 250° for four hours.

All the products of these heatings were leached with water, and washed until the filtrates gave no test for silver; the residues were then dried on the water bath. The product in each case was a white powder not differing in appearance from the original material.

The analyses of the different portions are given below, together with the composition of the theoretical compound, $AgAlSi_2O_6.H_2O$, which is given in column D.

	A.	B.	C.	D.
SiO_2	41.31	40.08	42.69	39.35
Al_2O_3	16.44	16.29	18.22	16.72
Ag_2O	37.45	36.91	32.01	38.03
Na_2O	.85	.81	.68	......
H_2O	4.29	5.86	6.08	5.90
NH_3			.69	......
Nitrates	none	none	none	......
	100.34	99.95	100.37	100.00

From preparation A, 13.13 per cent of the soda in the original mineral was found in the leach water; and in B, 12.57 per cent. These quantities are slightly in excess of the amount actually present in the analcite, for the reason that a little other material which passed into

the filtrates was not separated from the soda. It is enough to show that a true silver analcite has been formed, and that the transformation is practically complete. A similar reaction takes place between silver nitrate and chabazite, but the product as yet has not been exhaustively examined. The reaction, it will be observed, is analogous to that by which silver ultramarine is produced, and it suggests a promising line of experimentation for the future.

LEUCITE.

Between analcite and leucite the closest analogies have long been recognized. The two minerals have similar composition, they resemble each other in crystalline form, and they yield, upon alteration, products of the same order. Recently also, analcite, like leucite, has been identified as a not uncommon constituent of volcanic rocks; analcite basalt being a good example. In view of these resemblances it was plainly desirable to compare the minerals by means of the ammonium chloride reaction, a task which has been performed with satisfactory results.

In a preliminary experiment a sample of leucite taken without regard to purity was heated with ammonium chloride to 350° in a sealed tube. Potassium chloride was formed corresponding to 18.06 per cent of potash, and in the leached residue 6.90 per cent of ammonia was found. The foreseen reaction had occurred, and more careful work was accordingly undertaken.

Our material consisted of a large, irregular crystal of leucite from Vesuvius, which yielded about 20 grams of the pure mineral. This was ground to a uniform sample, and a portion of it was analyzed; the analysis will be given presently. The sealed-tube experiments were conducted precisely as in the case of analcite, and they confirmed both the preliminary test and our anticipations. Chlorides were formed equivalent to 18.53 per cent of potash, 1.08 of soda, and 0.08 of alumina; the reaction, therefore, was very nearly complete. The leached residue was then analyzed, and the data, compared with the analysis of the original mineral, were as follows:

	Leucite.	Residue.
SiO_2	55.40	60.63
Al_2O_3	23.69	26.44
CaO	.16	trace
K_2O	19.54	.50
Na_2O	1.25	.25
NH_3		7.35
H_2O	.24	5.17
	100.28	100.34

Leucite, then, gives the same reaction as analcite and yields the same ammonium compound. A closer agreement in the composition of the latter could not reasonably be demanded. Ammonium leucite is formed in both cases by ordinary double decomposition in a state of approximate purity; the first silicate of ammonium, we think, which has ever been prepared.

As a further check upon the results so far obtained, an attempt was made to transform ammonium leucite into the corresponding lime salt, $CaAl_2Si_4O_{12}$, by fusion with calcium chloride. The ammonium leucite was mixed with a saturated solution of calcium chloride, which was evaporated to dryness, then heated gradually to dehydration, and finally fused. Ammonium chloride was given off and identified. Upon treating the fused mass with water, filtering and thoroughly washing the residue, a white powder was obtained which, after drying at 100°, was analyzed. It was also examined microscopically by Mr. J. S. Diller, who found it to consist of apparently isotropic grains, showing traces of incipient crystallization. The following analysis is contrasted with the theoretical composition of calcium leucite, from which it varies considerably.

	Found.	Calculated.
SiO_2	54.35	60.30
Al_2O_3	26.23	25.63
CaO	17.38	14.07
K_2O	.16	
Na_2O	.25	
Cl	.28	
Loss on ignition	1.24	
	99.89	100.00

Evidently the desired salt was not definitely obtained, and the product appears to be a mixture. The reaction, however, tends in the right direction, and deserves further study under other conditions. Probably the water which was present in the mixture of silicate and chloride took part in the changes produced, although of this we can not be certain. It is interesting to note that the product obtained approximates in composition to the meteoric mineral maskelynite, which is regarded by Groth as probably equivalent to a calcium leucite.

THE CONSTITUTION OF ANALCITE AND LEUCITE.

In all of the earlier attempts to discuss the constitution of analcite the molecule of water which it contains has been a chief element of *uncertainty*. *Should* it be regarded as representing hydroxyl or as

water of crystallization? That question arose first of all. Under the first interpretation analcite became a diorthosilicate: $AlNaH_2Si_2O_7$; under the latter its equivalency with leucite appeared. The researches of Friedel, however, have settled this question in part, and whatever the function of the water may be it is something outside of the true chemical molecule; for all the water can be expelled from analcite by heat, without destruction of the crystalline nucleus, the anhydrous salt, and it is taken up again upon exposure of the dehydrated mineral to moist air. But whatever its mode of union may ultimately prove to be, the amount of water in analcite corresponds to the simple molecular ratio which is shown in the ordinary formula of the species. One molecule of analcite holds a certain definite number of water molecules, and Friedel's observations are not incompatible with the idea that these are retained with varying degrees of tenacity. This idea is suggested by the various series of fractionation experiments which have been made from time to time by independent workers, even though the data are not by any means concordant. Thus Lepierre[a] found that half the water of analcite was driven off at or below 300°, the other half above 440°. In our own experiments three-fourths were expelled at 300°, the remaining fourth being held up to a much higher but undetermined temperature. In both series the water fractions are represented by fourths, but Friedel's experiments[b] indicate a continuity of loss in weight of a quite dissimilar order. Friedel holds that all of the water fractionations heretofore made upon analcite are fallacious, and that no definite fractions can be identified—a conclusion strongly supported by his own data, even though the proof is not absolutely positive. The most that can be said is that the weight of evidence so far is in favor of Friedel's contention, but that additional investigation is necessary in order to reconcile all discrepancies. The full significance of the water in analcite remains unknown.

Eliminating the water from analcite, the empirical formulæ for both analcite and leucite appear at once to be identical in form and to represent salts of ordinary metasilicic acid. Indeed, both minerals have been commonly regarded as metasilicates; but upon this point the production of the ammonium derivatives now sheds a new light. In the formation of the latter compounds the fixed bases of the original salts have been replaced by a volatile base, and the substances so formed split up upon ignition in such a way as to give evidence regarding their constitution.

For example, if ammonium leucite is a true metasilicate, a salt of the acid H_2SiO_3, it should break up, when ignited, in accordance with the following equation:

$$2NH_4Al(SiO_3)_2=Al_2(SiO_3)_3+2NH_3+H_2O+SiO_2;$$

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[a] Bull. Soc. chim. France, 3d series, Vol. XV, p. 561, 1896.
[b] Bull. Soc. min. France, Vol. XIX, p. 363, 1896.

that is, one-fourth of the silica ought to be set free, measurable by extraction with sodium carbonate solution. No such splitting off occurs, however. An ammonium leucite which already contained 1.97 per cent of soluble silica gave only 1.70 per cent after ignition; hence no additional silica had been liberated. We may conclude, therefore, that analcite and leucite are not true metasilicates, but pseudo-compounds, either salts of a polymer of metasilicic acid or mixtures of ortho- and trisilicates analogous to those which we find among the plagioclase feldspars and in the mica group.

In order to discuss the constitution of analcite, let us recur to our analysis of the variety from Nova Scotia. It is at once evident from the comparison made on a preceding page that our sample of the mineral varies notably in composition from the requirements of theory. The silica is $2\frac{1}{2}$ per cent too high, while alumina and soda are correspondingly low. No probable impurity and no presumable errors of manipulation can account for so great a divergence. If we consult other analyses, as we find them tabulated in manuals like those of Dana and Hintze, we shall find other cases resembling this, and also examples of variation in the opposite direction, with silica low and an apparent excess of bases. Most analcite gives quite sharply the metasilicate ratios required by the accepted formula; but the variations from it are large enough, common enough, and regular enough to command attention. The analyses are not all covered by the recognized theory, and the apparent irregularities are not fortuitous, but are systematic in character.

One explanation of the seeming anomalies is simple and clear. If analcite, instead of being a metasilicate, is really a mixture of ortho and trisilicate, then all of the analyses become intelligible. In most cases the two salts are commingled in the normal ratio of 1:1, but in our analcite the trisilicate predominates, while in some other samples the ortho-salt is in excess. All reduce alike to the simple expression

$$NaAlX.H_2O,$$

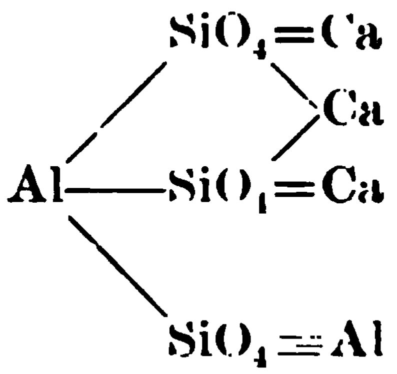
in which X represents $nSiO_4+mSi_3O_8$, a formula which agrees with evidence from various other sources.

For example, analcite may be derived in nature either from albite, $AlNaSi_3O_8$, or nephelite, $AlNaSiO_4$, and on the other hand alterations of it into feldspars have been observed. Its closest analogue, leucite, has yielded pseudomorphs of orthoclase and elæolite, while leucite and analcite are mutually convertible each into the other. The evidence of this character—the evidence of relationship between analcite and other species—is varied and abundant, and the simplest conclusion to be drawn from it is that which has been given. Every alteration, every derivation, every variation in the composition of analcite points to the same belief. The consistency of the data can not well be *denied.*

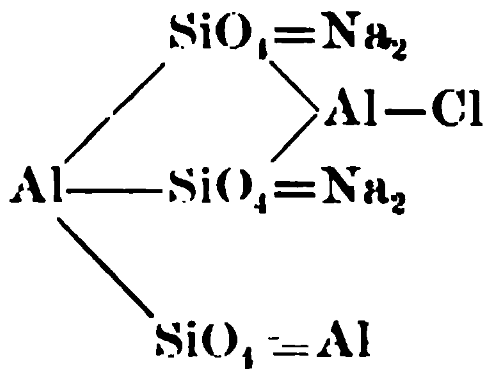
In the case of a normal analcite—that is, one which conforms to the usual empirical formula—the expression which best represents these relations is

$$Al_4Na_4\,(SiO_4)_2\,(Si_3O_8)_2 \cdot 4H_2O;$$

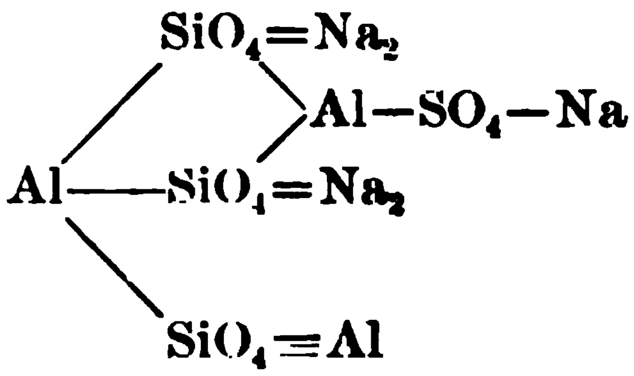
and leucite is the corresponding potassium salt, but anhydrous. Structurally this is comparable with the formulæ of garnet, zunyite, sodalite, and noselite, all of which are isometric in crystallization. The more important of the symbols are as follows:



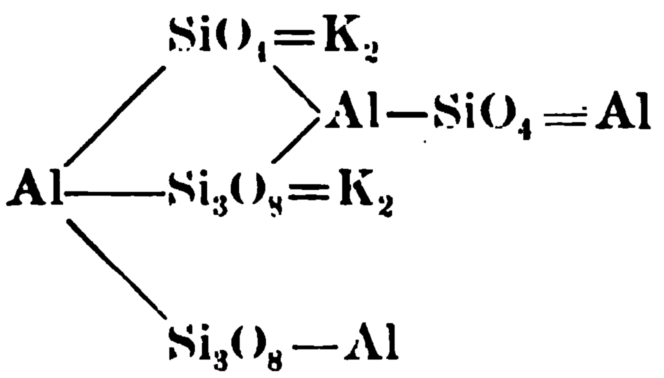
Garnet.



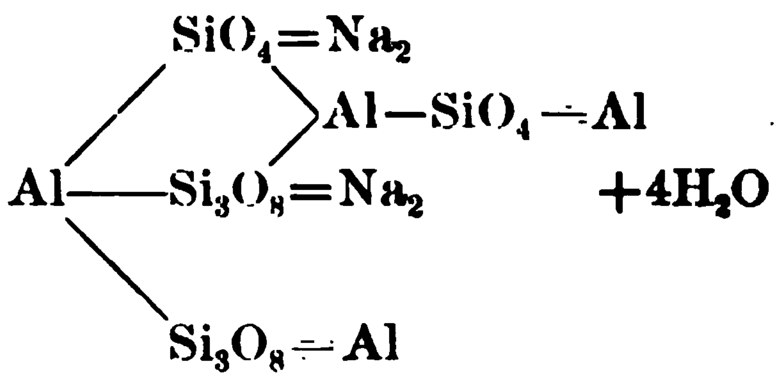
Sodalite.



Noselite.

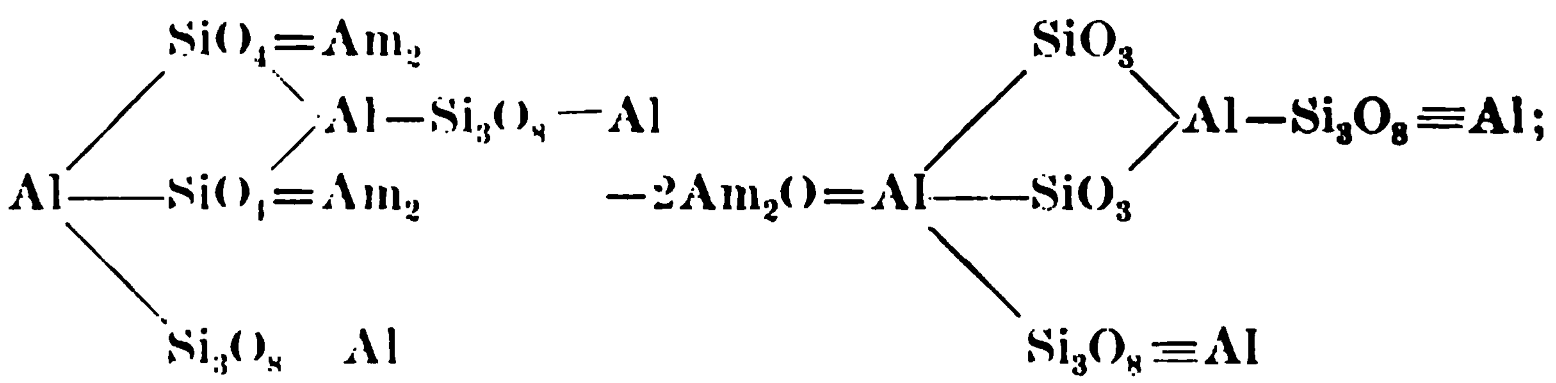


Leucite.



Analcite.

That is, analcite and leucite become members of the garnet-sodalite group of minerals, and their relations to nephelite, albite, etc., natural and artificial, are perfectly clear. In analcite there may be admixtures of strictly analogous ortho- or trisilicate molecules; but these remain to be separately discovered. The ammonium salt corresponding to such a mixture, when ignited, might be expected to give the following reaction:



a reaction which is in harmony with our experimental results. In it no free silica appears; and many, if not all, conditions of the problem are satisfied. One difficulty, however, stands in the way of an unqualified acceptance of these formulæ. Garnet, sodalite, nephelite, albite, etc., are but moderately attacked by ammonium chloride, and so far have yielded no definite ammonium derivatives. Whether this difference in behavior is constitutional or not it is hardly possible to say, but it must be taken into account in connection with all of the other evidence. We must remember, moreover, that the formulæ

are not ultimate verities to be blindly accepted. They are simply expressions which represent composition and a wide range of established relationships, and which serve a distinct purpose in the correlation of our knowledge. Properly used, with due recognition of their limitations, they are helpful, and suggest possibilities of research; misused, they may become mischievous. They now satisfy most of the known conditions, and that is a sufficient warrant for their existence.

POLLUCITE.

On account of the general analogy between pollucite, analcite, and leucite, the first-named species of the three seemed to deserve some attention. Through the kindness of Prof. S. L. Penfield, about 10 grams of very pure material from Hebron, Me., was put at our disposal, and three analyses of it by Wells were already on record.[a] The average of these analyses is as follows:

SiO_2	43.53
Al_2O_3	16.37
CaO	.22
Na_2O	1.81
K_2O	.49
Li_2O	.04
Cs_2O	36.08
H_2O	1.52
	100.06

Five grams of the finely powdered mineral was heated in a sealed tube with four times its weight of ammonium chloride to 350° during forty hours. Upon leaching with water 0.14 per cent of CaO, 1.28 of Na_2O, and 12.30 of Cs_2O were extracted. Probably the calcium chloride formed contained some potassium chloride, but that point was ignored as irrelevant. The air-dried residue had the following composition:

SiO_2	49.21
Al_2O_3	18.32
CaO	none
Cs_2O (K_2O)	28.84
Na_2O	none
NH_3	2.52
H_2O	1.91
	100.80

The high summation here is due to reckoning some KCl as CsCl. Of the silica in this product 2.36 per cent was soluble in the standard solution of sodium carbonate. After ignition, 4.13 per cent was soluble. Some silica, therefore, was split off by heating.

[a] Am. Jour. Sci., 3d series, Vol. XLI, p. 213, 1891.

In a second experiment one gram of pollucite was heated with ammonium chloride for five hours, the other conditions being the same as before. Upon leaching, 11.55 per cent of Cs_2O was extracted, and a partial analysis of the air-dried residue gave the following data:

SiO_2	47.87
Al_2O_3	17.85
NH_3	2.83
H_2O	1.55
Alkalies (by difference)	29.90
	100.00

The two products were evidently the same, and only about one-third of the alkalies in the pollucite had been extracted. So, also, the ammonia taken up was only about one-third of that which was retained by analcite and leucite. The transformation, then, is merely partial, and further experimentation seems to be unnecessary, at least for present purposes. The analogy with analcite and leucite is far from perfect.

NATROLITE.

In a preliminary experiment upon an impure, yellowish natrolite from Aussig in Bohemia, we found that this species was peculiarly well suited to reaction with ammonium chloride. By heating with the reagent in a sealed tube and subsequent leaching with water, 17.56 per cent of bases was extracted, and in the residue 8.29 per cent of ammonia was found. Careful work upon this species was therefore desirable.

The material available for our experiments came from the well-known locality at Bergen Hill, N. J., and consisted of a mass of slender needles densely matted together. Part of the uniform, ground sample was analyzed, with fractional determinations of the water, and part was used for the sealed tube experiments, precisely as in the research upon analcite and leucite. Three of these experiments were made, and in each case the natrolite was mixed by grinding in an agate mortar with four times its weight of dry ammonium chloride, after which it was heated to 350° in the sealed tube. Even during the grinding a slight reaction took place, and a distinct smell of ammonia was given off by the mixture. With pectolite the same smell was perceived. The three experiments may be summarized as follows:

A. Heated eleven hours. Upon leaching, 14.89 per cent of soda and 1.20 of lime were extracted. In the residue 9.26 per cent of ammonia was found.

B. Heated nine hours. Leach not examined. 9.26 of ammonia in residue. The complete analysis of the residue is given farther on.

C. Heated three hours. 14.09 per cent of soda and 0.20 of lime were extracted. The residue contained 8.87 per cent of ammonia. In this instance the heating

was relatively brief, in order to learn whether its duration could be advantageously lessened. The reaction was evidently less complete than in experiments A and B.

In the subjoined table we give first the analysis of the natrolite itself, and then that of the leached residue from experiment B. In the latter we found that 0.86 per cent of silica was soluble in sodium carbonate solution, and that soda and lime remained corresponding to 4.61 per cent of the original mineral. Deducting these impurities, together with the 0.42 per cent of hygroscopic water, and recalculating to 100 per cent, we get the *reduced* composition of the residue. In the last column is given the calculated composition of an anhydrous ammonium-natrolite, $(NH_4)_2Al_2Si_3O_{10}$. This compound has evidently been formed to an extent represented by over 94 per cent of the leached natrolite residue. The agreement between theory and even the unreduced analysis is practically conclusive on this point.

	Natrolite found.	Residue found.	Residue reduced.	$(NH_4)_2Al_2Si_3O_{10}$ calculated.
SiO_2	46.62	53.71	53.86	54.06
Al_2O_3	26.04	29.94	30.52	30.43
CaO	1.48	.34		
K_2O	none			
Na_2O	15.67	.37		
NH_3		9.26	9.85	10.14
H_2O at 100°	.39	.42		
H_2O above 100°	10.18	5.94	5.77	5.37
	100.38	99.98	100.00	100.00

The fractional water determinations will be given later, in connection with similar data for scolecite (p. 25).

It may not be superfluous to note that the water given in the last two columns of the foregoing table represents the difference between ammonia and the hypothetical ammonium oxide which has replaced soda.

Two other experiments upon natrolite remain to be noticed. First, the fresh mineral was boiled for fifteen minutes with a 25 per cent sodium carbonate solution; 0.72 per cent of silica dissolved. Similar treatment of ignited natrolite took out 0.62 per cent. No silica is split off by ignition. Ammonium natrolite before ignition yielded 0.85 per cent of soluble silica, and after ignition 0.86 per cent. Here again no silica had been split off from the molecule, and practically none was liberated by the action of the ammonium chloride upon the natrolite. A simple, direct substitution of ammonium for sodium *had occurred.*

Heated with ammonium chloride in an open crucible, natrolite gives only a partial reaction. This is shown by the earlier experiments of Schneider and Clarke upon natrolite from Magnet Cove, Arkansas, from which, by a triple heating with the reagent, only 9.50 per cent of soda was extracted out of a total of 15.40.

SCOLECITE.

On account of the well-recognized analogy between natrolite and scolecite, the latter mineral seemed to be peculiarly worthy of examination. The specimen at our disposal was a mass of stout, radiating needles, which was collected by one of us at Whale Cove, on the island of Grand Manan, New Brunswick. Scolecite, we believe, has not hitherto been recorded from this locality, and on this account alone the material deserved attention.

Three sealed tube experiments were carried out, essentially as in the case of natrolite, as follows:

A. Heated ten hours at 350°. 13.74 per cent of lime and 0.35 of soda were taken out. The residue contained 8.78 per cent of ammonia.

B. Heated ten hours at 370°. 12.97 of lime and 0.22 of soda were extracted. 8.48 per cent of ammonia in the residue. On account of the excessive temperature of this experiment, some reversion of the converted material had taken place.

C. Heated five hours at 340°–350°. Leach not studied. 8.91 per cent of ammonia in residue.

Analyses of the scolecite and of residues B and C are given below. The less perfect transformation in the case of B is evident.

	Scolecite.	Residue B.	Residue C.
SiO_2	45.86	53.39	53.69
Al_2O_3	25.78	30.51	30.50
CaO	13.92	.62	.42
Na_2O	.41	undet.	.29
NH_3		8.48	8.91
H_2O at 100	.40	.74	.12
H_2O above 100°	13.65	6.28	6.52
	100.02	100.02	100.45

The product of the reaction is plainly the same as that obtained from natrolite, and the identity in type of the two species is perfectly clear. This fact is further emphasized by an experiment upon the solubility of silica. The fresh scolecite gave up 0.36 per cent of silica to sodium carbonate solution, and the ignited mineral yielded only 0.50 per cent. Again, natrolite and scolecite behave in the same way.

Upon both minerals fractional determinations of the water were *made, and the amount* lost at each temperature was noted. The

results, expressed in percentages of the original minerals, were as follows:

Temperature.	Water lost.	
	Natrolite.	Scolecite.
100°	0.39	0.40
180°	.40	.52
250°	.37	4.76
350°	8.51	.55
Incipient redness	.72	7.72
Full redness	.12	.04
Over blast	.06	.06
	10.57	14.05

Scolecite contains one more molecule of water than natrolite, and that amount, one-third of its total, seems to go off at a lower temperature than the other two molecules. Otherwise the two series of experiments are probably not far apart, and they indicate that the water is in neither case constitutional. The same conclusion is suggested by the existence of the anhydrous ammonium compound, the three formulæ being as follows:

Scolecite	$CaAl_2Si_3O_{10}.\ 3H_2O$
Natrolite	$Na_2Al_2Si_3O_{10}.\ 2H_2O$
Ammonium natrolite	$(NH_4)_2Al_2Si_3O_{10}$

The parallelism is complete; and all three compounds are evidently salts of an acid, $H_8Si_3O_{10}$, which is probably orthotrisilicic acid, $Si_3O_2(OH)_8$. The relations of this acid to its anhydrides will be considered later.

PREHNITE.

In a former bulletin upon the constitution of the silicates,[a] one of us attempted to show that natrolite, scolecite, and prehnite were similar in chemical structure, provided that all or part of their water was regarded as constitutional. The formulæ then assigned were as follows:

Scolecite	$Al_2(SiO_4)_3CaH_4.\ H_2O$
Natrolite	$Al_2(SiO_4)_3Na_2H_4$
Prehnite	$Al_2(SiO_4)_3Ca_2H_2$

Two of these formulæ must now be abandoned, because of the experimental evidence which we have obtained, but the prehnite remains to be considered.

[a] Clarke, F. W., Bull. U. S. Geol. Survey No. 125, p. 45, 1895.

The material chosen for examination was an old specimen of prehnite from Paterson, N. J. The analysis of it, with fractional water determinations, is given below:

SiO_2	42.31
Al_2O_3	19.95
Fe_2O_3	6.20
FeO	none
CaO	26.63
H_2O	5.02
	100.11

Fractional water.

At 100°	0.21
At 180°	.18
At 250°	.10
At 350°	.11
Incipient red heat	.28
Full red heat	4.05
Over blast	.09
	5.02

With sodium carbonate sulution, 0.38 per cent of silica was extracted from the fresh mineral. From the ignited prehnite, 1.22 per cent was taken out. Very little silica, therefore, is liberated by ignition.

Two determinations were made of the action of ammonium chloride, as follows:

A. Heated eight hours. On leaching with water, 1.31 per cent of lime and 0.17 of alumina dissolved.

B. Heated twelve hours. 1.41 per cent of lime was extracted, and in the washed residue 0.22 per cent of ammonia was found.

Prehnite, therefore, differs widely from natrolite and scolecite in its behavior with ammonium chloride. Very little action takes place, even upon long heating to 350° in a sealed tube, and practically no ammonia is absorbed. The water is more firmly held than was the case with the other two minerals, and is almost certainly to be regarded as constitutional. The orthosilicate formula for prehnite is unaffected by these results, and may stand as fairly probable. Prehnite can not be correlated with natrolite and scolecite on any basis of similar chemical structure.

THE TRISILICIC ACIDS.

We have already shown that natrolite and scolecite are probably salts of an orthotrisilicic acid, $H_8S_3O_{10}$, an acid which is not particularly well known. As it has interesting relations to other compounds, some discussion of its constitution and its derivatives may not be out of place here.

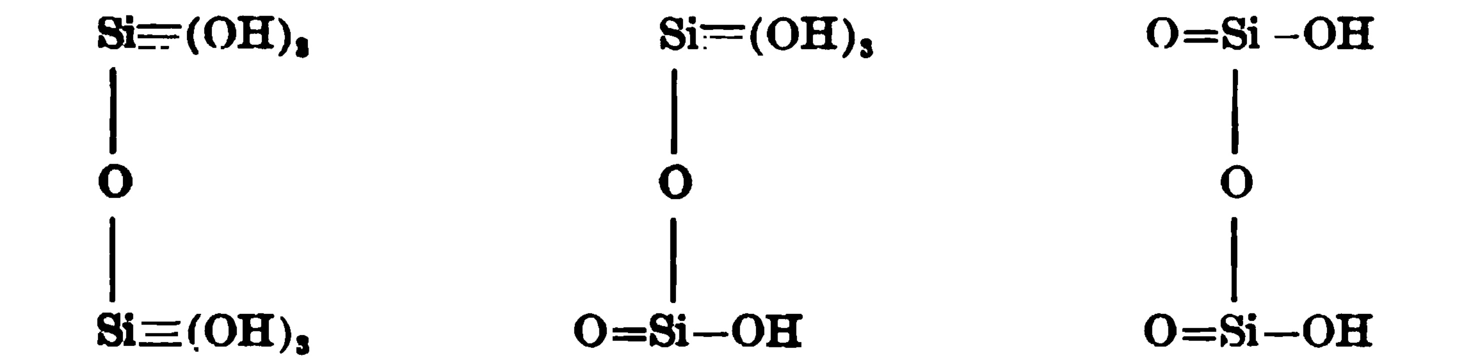
The general theory of the silicic acids is extremely simple. Silicon *being a quadrivalent* element, its normal acid, the orthosilicic, is

$Si(OH)_4$. From this, by successively eliminating two molecules of water, two anhydrides may be derived, thus:

Orthosilicic acid	$Si(OH)_4$
First anhydride, metasilicic acid	$O=Si-(OH)_2$
Second anhydride, silicon dioxide	$O=Si=O$

These acids, containing one atom of silicon each, may be called the monosilicic acids, and some of their salts are perfectly well known. Olivine and anorthite, for instance, are orthosilicates, while the true metasilicates are represented by talc and pectolite. The evidence in the case of the last-named mineral will be presented later.

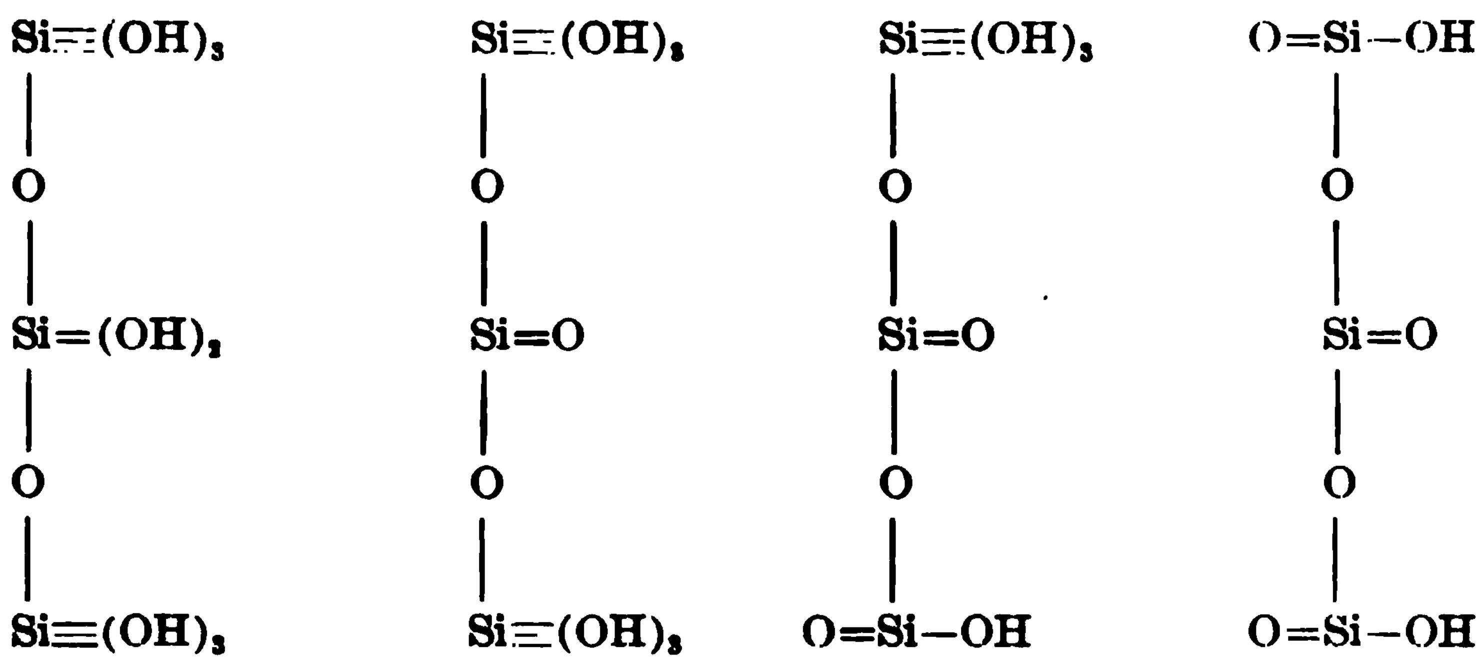
When two molecules of orthosilicic acid coalesce, with elimination of water, an orthodisilicic acid is formed, and this is the first member of another series, as follows:



Orthodisilicic acid. *Metadisilicic acid.* *Pyrosilicic acid.*

To the first and third of these acids various minerals correspond. The second acid, however, is a polymer of metasilicic acid, but differs from the latter in its possible derivatives. When an acid metasilicate is heated silica is set free, but in the case of a metadisilicate this would not necessarily occur. Possibly leucite and analcite may be metadisilicates, although the evidence so far presented does not support this view. The possibility, however, we are compelled to recognize as one which might ultimately be verified.

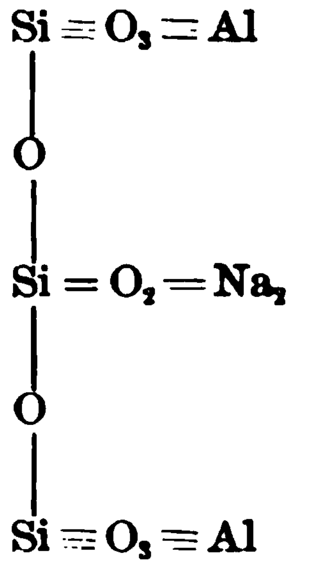
With the coalescence of three orthosilicic molecules a series of trisilicic acids begins, and one of these forms salts—the feldspars—which are the most abundant compounds existing in the mineral kingdom. The acids of the series are these:



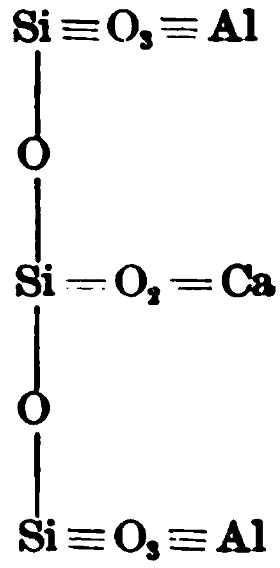
Orthotrisilicic acid. *Metatrisilicic acid.* Trisilicic acid. Third anhydride.

The third anhydride represents an acid to which no known salts correspond. One step further and we have a fourth anhydride, Si_3O_6, or empirically SiO_2, which may or may not be the true formula of quartz. Quartz is undoubtedly a polymer of SiO_2; its most frequent associates are trisilicates—the feldspars—and hence the formula Si_3O_6 has a certain degree of plausibility. This suggestion, however, is purely speculative and has no definite scientific value. Its validity would be most difficult to establish.

From the first of these trisilicic acids natrolite and scolecite appear to be derived. If we ignore the "zeolitic water," which is not a part of the essential silicate molecule, the two compounds may be formulated thus:



Natrolite.



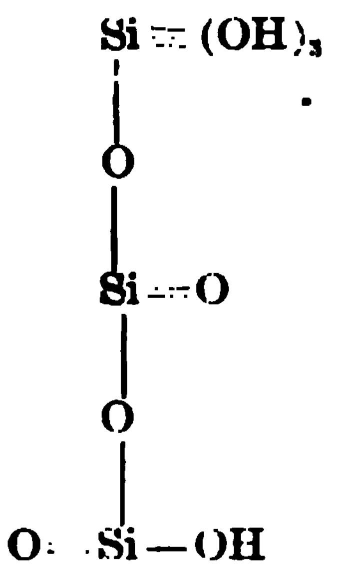
Scolecite.

So far, no other salts of this acid have been clearly identified.

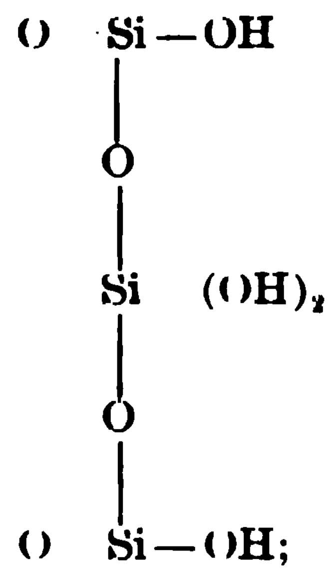
The second acid of the series, like the second of the disilicic acids, is a polymer of the ordinary metasilicic compound. It is well understood that many so-called metasilicates are not representatives of the simple acid H_2SiO_3; some of them are mixtures of orthosilicates with salts of the third acid in this group, $H_4Si_3O_8$; others may be derived from polymers like that which is now under consideration. For example, anhydrous analcite and jadeite are both represented by the empirical formula $NaAlSi_2O_6$, but they differ widely in density, in solubility, and doubtless also in crystalline form. One molecule, then, is much more condensed than the other. If analcite should prove to be a metadisilicate, then jadeite may be its equivalent in the trisilicic series, or it may belong with some still higher polymer. The possibilities are many, but to establish any one of them by proof would demand more evidence than is yet in our possession.

The third member of the trisilicic series is the most important of all, for among its salts are the two feldspars, albite and orthoclase, which together make up fully one-half of the solid crust of the earth. It is also noteworthy from the fact that its formula can be so written

as to represent two isomeric forms, to which distinct salts probably correspond. The two formulæ are as follows:



and



and their significance is clear when we remember that the ordinary trisilicates are commonly dimorphous. Thus we have orthoclase and soda orthoclase, monoclinic; and albite and microcline triclinic; one pair perhaps belonging to one isomer, the other to the other. The rare minerals eudidymite and epididymite, which are also isomeric trisilicates, further illustrate the same conception; but we can not as yet assign either compound distinctly to either formula.

By an extension of the process herein developed, which is by no means new, higher polysilicic series may be formulated. Since, however, such acids correspond to no definitely known salts, to write their formulæ would be a useless exercise of the imagination. Beyond the trisilicic acids we enter the region of the unknown.

STILBITE.

The specimen selected for study was a nearly white, typical example from Wassons Bluff, Nova Scotia. The analysis and the fractional water determinations were as follows:

SiO_2	55.41
Al_2O_3	16.85
Fe_2O_3	.18
MgO	.05
CaO	7.78
Na_2O	1.23
H_2O	19.01
	100.51

Fractional water.

At 100°	3.60
At 180°	6.46
At 250°	3.80
At 350°	2.10
Low redness	2.95
Full redness	.06
Over blast	.04
	19.01

On boiling with sodium carbonate, 1.37 per cent of silica went into solution. After ignition, only 1.03 per cent was obtained. No silica, therefore, is split off when stilbite is ignited. If the mineral were a hydrous acid metasilicate, $H_4CaAl_2Si_6O_{18}.4H_2O$, as has been assumed by some authorities, one-third of the silica should have been set free. Hence the metasilicate formula is to be regarded as unsatisfactory. The evidence here presented counts for something against it.

Two samples of the ammonium chloride derivative were prepared. In leaching with water the insoluble residue was washed until the washings gave no reaction for chlorine. The chlorine shown in the subjoined analyses is, therefore, present in an insoluble form and not as adhering ammonium chloride. Dried at 50° the two products gave the following composition:

	A.	B.
SiO_2	60.80	60.67
Al_2O_3	18.36	18.25
CaO	1.86	1.46
Na_2O	.08	.15
NH_3	5.12	5.13
H_2O	12.96	13.91
Cl	1.31	1.04
	100.49	100.61
Less O	.29	.23
	100.20	100.38

Sample B was further examined as to the presence of soluble silica, and 1.52 per cent was found. After ignition, only 1.62 per cent went into solution. These results conform to those obtained with the original stilbite, and tend to show that the ammonium derivative is a compound of the same order. In the case of the unignited substance the residue remaining after the removal of soluble silica was thoroughly washed, and then examined for alkali. It was found to contain 9.30 per cent of soda, which shows that the ammonium salt had been transformed back into the corresponding sodium compound.

From the foregoing facts it is clear that stilbite, like the zeolites previously studied, is converted by the action of ammonium chloride into an ammonium salt. That is, sodium and calcium are removed as chlorides, ammonium taking their place to form ammonium stilbite. The reaction, however, is less complete than it was in the cases of analcite and natrolite, but whether this is due to a greater stability of the stilbite molecule or only to a different degree of fineness in the powder upon which the operations were performed, we can not say. Neither have we any explanation to offer of the retention of chlorine

by the ammonium derivative. Although the amount of chlorine is small, it needs to be accounted for.

If we discuss the composition of the stilbite and of its ammonium derivative, the relations between them become very clear. Neglecting the water as "zeolitic," to use Friedel's phrase, and, therefore, as not a part of the chemical molecule, and also rejecting the 1.37 per cent of soluble silica as probably an impurity, the ratios derived from the analysis give this empirical formula for the mineral:

$$Na_{40}Ca_{110}Al_{332}Si_{901}O_{2460}.$$

This corresponds to a mixture of ortho- and trisilicates in which $Si_3O_8:SiO_4::286:43$; and uniting these radicles under the indiscriminate symbol X, we have, as a more general expression,

$$Na_{40}Ca_{140}Al_{332}X_{326};$$

or combining monoxide bases,

$$R''_{160}Al_{332}X_{329},$$

which is essentially $R''Al_2X_2$. Since the SiO_4 groups are practically equal in number to the sodium atoms, the stilbite is probably a mixture, very nearly, of $NaAlSiO_4$ and $CaAl_2(Si_3O_8)_2$ in the ratio of 1:7 This is in accordance with the well-known theory of Fresenius as to the constitution of the phillipsite group, to which stilbite belongs. Stilbite is mainly a hydrous calcium albite, commingled with varying amounts of corresponding orthosilicates of soda and lime.

For the ammonium derivative similar relations hold. Taking analysis "B" for discussion, rejecting soluble silica and chlorine as impurities, and neglecting all water except that which belongs to the supposable ammonium oxide, the ratios give this formula:

$$(NH_4)_{301}Na_4Ca_{26}Al_{358}Si_{985}O_{2684}.$$

Uniting sodium and calcium with ammonium, this becomes

$$R'_{357}Al_{358}(Si_3O_8)_{314}(SiO_4)_{43};$$

or, more generally,

$$R'_{357}Al_{358}X_{357}, = 1:1:1.$$

The derivative, therefore, is a compound of the same order as the original stilbite, with the ratio of 1:7 still holding between the ortho and trisilicate groups. This conclusion, however, ignores the presence of chlorine, and is, therefore, inexact to some extent. We are not dealing with ideally pure compounds.

HEULANDITE.

Pure, white heulandite from Berufiörd, Iceland, was the material taken for investigation. Upon boiling with sodium carbonate, 1.73 per cent of silica went into solution. From previously ignited heulandite, only 1.14 per cent was extracted. No silica, therefore, was liberated upon ignition, and a hydrous metasilicate formula for the mineral seems to be improbable. Only one lot of the ammonium

chloride derivative was prepared, and its composition, together with that of the heulandite, is given below.

	Heulandite.	Ammonium salt.
SiO_2	57.10	61.24
Al_2O_3	16.82	18.00
MgO	.07	....
CaO	6.95	2.56
SrO	.46	....
Na_2O	1.25	.60
K_2O	.42	
NH_3	....	4.42
H_2O at 100	3.61	13.63
H_2O above 100	13.00	
	99.68	100.45

Here, again, we have the same kind of transformation as before, but rather less complete than in the case of stilbite. That the ammonium taken up is equivalent to the bases removed is shown by a study of the ratios. Ignoring water and the soluble silica, the heulandite ratios are as follows:

$$R'_{48}R''_{130}Al_{330}Si_{923}O_{2495},$$

or, uniting bases,

$$R''_{154}Al_{330}(Si_3O_8)_{300}(SiO_4)_{24}.$$

Again simplifying, this becomes

$$R''_{154}Al_{330}X_{324},$$

or very nearly 1 : 2 : 2, as in stilbite.

Similarly discussed, the ammonium salt gives the ratios

$$R'_{270}Ca_{46}Al_{352}Si_{1021}O_{2746},$$

equivalent to

$$R'_{362}Al_{352}X_{353}, \text{ or } 1:1:1.$$

In both cases the orthosilicate molecules are few, and the compounds approximate to trisilicates very closely.

CHABAZITE.

Characteristic flesh-colored crystals from Wassons Bluff, Nova Scotia. The analysis and fractional water determinations are—

SiO_2	50.78
Al_2O_3	17.18
Fe_2O_3	.40
MgO	.04
CaO	7.84
Na_2O	1.28
K_2O	.78
H_2O	21.85
	100.10

Fractional water.

At 100°	5.22
At 180°	5.70
At 250°	3.92
At 350°	2.36
Low redness	4.51
Full redness	.13
Over blast	.01
	21.85

The unignited mineral, upon boiling with sodium carbonate, gave 0.86 per cent of soluble silica. After ignition only 0.53 per cent was soluble. Here again no silica is liberated by calcination, and metasilicate formulæ may be disregarded.

Two samples of the ammonium chloride derivative were prepared, which after thorough washing were dried at 40° to 50°. As in the case of stilbite, small quantities of chlorine appear in the compound, not removable by washing. The amount of change effected is also somewhat less than with stilbite, and about the same as with heulandite. The analyses of the two samples are subjoined, with the remaining alkali all reckoned as soda:

	A.	B.
SiO_2	55.88	56.09
Al_2O_3	19.15	19.49
CaO	2.25	2.01
$Na_2O(K_2O)$	.35	.24
NH_3	4.64	4.83
H_2O	16.57	16.01
Cl	.95	1.35
	99.79	100.02
Less O	.21	.30
	99.58	99.72

In B, 1.50 per cent of soluble silica was found. After ignition this was reduced to 1.12 per cent. No liberation of silica accompanies the splitting off of water and ammonia.

Upon studying the molecular ratios for chabazite and its derivative, relations appear precisely like those found for stilbite and heulandite. For chabazite itself, rejecting water and the 0.86 per cent of soluble silica, we have

$$R'_{58}Ca_{141}Al_{310}Si_{832}O_{2344},$$

or, consolidating soda with lime,

$$Ca_{170}Al_{310}(Si_3O_8)_{246}(SiO_4)_{94}.$$

One step further and this becomes

$$Ca_{170}Al_{340}X_{340}=1:2:2.$$

Treating derivative "B" in the same way, and ignoring chlorine as an unexplained impurity, the analysis gives

$$(NH_4)_{284}Na_8Ca_{35}Al_{382}(Si_3O_8)_{266}(SiO_4)_{112};$$

or, consolidating bases as before,

$$R'_{362}Al_{382}X_{378}=1:1:1 \text{ nearly.}$$

The assumption of commingled ortho- and trisilicate molecules conforms to Streng's theory of the constitution of chabazite.

THOMSONITE.

The compact-fibrous variety from Table Mountain, near Golden, Colo. Analytical data as follows:

SiO_2	41.13
Al_2O_3	29.58
CaO	11.25
Na_2O	5.31
H_2O	13.13
	100.40

Fractional water.

At 100°	1.01
At 180°	1.44
At 250°	1.05
At 350°	3.90
Low redness	5.65
Over blast	.08
	13.13

Before ignition the mineral yielded 0.45 per cent of silica to sodium carbonate solution. After ignition 0.68 per cent was soluble. The difference is trifling.

Two samples of the ammonium chloride derivative were prepared. In A the heating was only to 300°, in B to 350°. Analyses of the leached products gave the following results:

	A.	B.
SiO_2	42.41	42.65
Al_2O_3	30.50	31.34
CaO	10.00	9.23
Na_2O	2.63	2.48
NH_3	2.45	2.67
H_2O	11.96	11.81
	99.95	100.18

In A, 1.80 per cent of soluble silica was found.

In this case the amount of change is very much less than with the zeolites previously examined. Little lime was removed, and only about half of the soda. Both samples were prepared with six hours of heating in the sealed tube, and it seemed to be desirable to determine whether a more prolonged treatment would produce any greater effect. Accordingly a third lot of thomsonite was mixed with ammonium chloride and heated in a sealed tube to 350° for twenty-four hours. The leached product contained 3.40 per cent of ammonia, a distinct increase over the other findings, although the amount of transformation into an ammonium salt was still only moderate.

We have already seen that stilbite, heulandite, and chabazite approximate more or less nearly to trisilicates in their composition. Thomsonite, however, is essentially an orthosilicate, with variable admixtures of trisilicate molecules. In the example under consideration, ignoring water and soluble silica, the molecular ratios give this formula:

$$Na_{172}Ca_{201}Al_{580}(Si_3O_8)_{50}(SiO_4)_{528};$$

or, condensing,

$$R''_{287}Al_{580}X_{578}=1:2:2.$$

Here the acid radicles are ten-elevenths orthosilicate. Ammonium derivative A, similarly computed, gives first—

$$(NH_4)_{144}Na_{84}Ca_{178}Al_{598}(Si_3O_8)_{44}(SiO_4)_{551};$$

or, uniting univalent bases with lime,

$$R''_{292}Al_{598}X_{595}=1:2:2;$$

the fundamental ratios being practically unchanged.

It will be observed that in all of these computations of formulæ we have assumed that all the water is "zeolitic;" that is, independent of the true chemical molecules. This question, however, needs to be separately investigated for each individual species. While the assumption is valid for some of these minerals, it is not necessarily valid for all. The real chemical differences between the zeolites are yet to be determined; our work merely proves that ammonium compounds are formed, completely in some cases, partially in others. The research should be extended to cover all the zeolites; but this task we must leave to other investigators.

LAUMONTITE.

Upon this species only one rather crude experiment has been tried, and that upon material of unknown origin. The mineral was heated with ammonium chloride in a sealed tube as usual, and then leached with water. 4.51 per cent of lime and 0.35 of soda were extracted, and in the residue 3.95 per cent of ammonia was found. Laumontite, therefore, behaves much like the other zeolites, and is only partially transformed into an ammonium compound.

PECTOLITE.

The pectolite which was chosen for examination was the well-known radiated variety from Bergen Hill, N. J. The mineral was in long white needles, and apparently quite pure, but the analysis shows that it contained some carbonate as an impurity. Enough of the material was ground up to furnish a uniform sample for the entire series of experiments, and the work properly began with a complete analysis. The results obtained are as follows:

SiO_2	53.34
Al_2O_3	.33
CaO	33.23
MnO	.45
Na_2O	9.11
H_2O	2.97
CO_2	.67
	100.10

Fractional water.

At 105°	0.27
At 180°	.16
At 300°	.22
At redness	2.32
	2.97

All of the water was given off at a barely visible red heat, and the figures show that practically all of it is constitutional—a fact which perhaps hardly needed reverification. The analysis gives the accepted formula for pectolite,

$$HNaCa_2Si_3O_9.$$

Does this represent, as is commonly assumed, a true metasilicate? If it does, we should expect that ignition would split off silica proportional to the acid hydrogen, or one-sixth of the total amount. To answer this question several portions of the pectolite were sharply ignited, to complete dehydration, and then boiled each for fifteen minutes with a solution of sodium carbonate containing 250 grams to the liter. In the extract so obtained the silica was determined, and the three experiments gave the following percentages:

	8.96
	8.67
	8.42
Mean,	8.68

One-sixth of the total silica is 8.89 per cent, and the experiments, therefore, justify the original expectation. The belief that pectolite is a metasilicate is effectively confirmed.

Upon the unignited pectolite the sodium carbonate solution has a slow decomposing action, both silica and bases being withdrawn. In two experiments fifteen minutes of boiling extracted 2.07 and 2.55 per cent of silica, and by a treatment lasting four days 4.80 per cent

was taken out. With water alone similar results were obtained, the action being so rapid, although relatively slight, that pectolite, moistened, gives an immediate and deep coloration with phenol phthalein. By boiling the powdered pectolite with distilled water alone, 1.65 per cent of silica was brought into solution, and the ignited mineral, similarly treated for fifteen minutes, gave 1.78 per cent. The extraction in these cases is really an extraction of alkaline silicate, as the two following experiments prove. In A the unignited pectolite was boiled for fourteen hours with distilled water, and in B the mineral after ignition was subjected to like treatment for four hours. The dissolved matter in each case was determined, with the subjoined results:

Extracted.	A.	B.
SiO_2	2.98	3.03
CaO	.30	.10
Na_2O	.81	1.50
	4.09	4.63

In A no simple ratio appears, but in B the extracted silicate approximates very nearly to the salt $Na_2Si_2O_5$. In each instance the ratios vary widely from those of the original mineral, showing that actual decomposition and not a solution of the pectolite, as such, has occurred.

Schneider and Clarke,[a] in their first experiments upon the ammonium chloride reaction, treated pectolite from Bergen Hill three times successively with the reagent and then leached out with water. In the solution 20.50 per cent of lime and 6.95 of soda were found, showing that a very considerable decomposition had taken place, but the residue was not examined. In a preliminary experiment by the sealed tube method we found that 20.72 per cent of lime and 6.46 of soda were taken out, while 1.44 per cent of ammonia was retained by the residue. That is, two-thirds of the bases, approximately, had been converted into chlorides by the reaction. The open crucible and the sealed tube gave essentially the same results, although the retention of ammonia was not noticed by Schneider and Clarke.

In order to obtain further light upon pectolite we continued our experiments with the sealed tube method, and have obtained very variable results. All of the heatings with ammonium chloride were conducted at 350°, and the pectolite used was from the same Bergen Hill specimen which served us for our previous work. Our data are as follows, including for convenience of comparison the preliminary experiment which was cited above:

A. Heated six hours. On leaching, 20.72 per cent of lime, 6.46 soda, and 0.11 alumina dissolved. The residue contained 1.44 per cent of ammonia.

[a] Bull. U. S. Geol. Survey No. 113, p. 34, 1893.

B. Heated six hours. 20.10 per cent lime and 5.80 of soda extracted. 1.45 per cent ammonia in the residue. The residue was also examined for silica soluble in 25 per cent sodium carbonate solution (on fifteen minutes boiling), and 43.38 per cent was found.

C. Heated six hours. Soluble portion neglected. The residue contained 2.23 per cent of ammonia and 61.79 per cent of soluble silica. The full analysis of this residue is given later.

D. Heated ten hours. A complex breaking up of the pectolite took place, and leaching with water extracted the following percentages:

SiO_2	5.43
Al_2O_3	.22
CaO	28.20
MnO	.23
Na_2O	8.29

The residue from this leaching contained 39.63 of soluble silica, but ammonia was not determined.

These results are so irregular that definite conclusions can hardly be drawn from them. A and B agree fairly with each other, and also with the earlier work of Schneider and Clarke. C contains more ammonia, but differs widely from B as to the amount of soluble silica in the residue. D, which represents a long heating, indicates a more complete reaction than was observed in either of the other cases.

An ammonium compound, however, is evidently formed during the reaction, although its precise nature can not be determined from the evidence now in hand. Something may be inferred from the following figures, which are to be summarized thus: First, we reproduce from our earlier paper the analysis of the pectolite itself. Secondly, we give the analysis of the insoluble residue obtained in experiment C. The third column of figures is obtained by subtracting from the second column 61.79 of soluble silica and 1.18 of hygroscopic water, and recalculating the remainder to 100 per cent. The fourth column contains the molecular ratios calculated from the third.

	Pectolite.	Residue found.	Residue reduced.	Ratios.
SiO_2	53.34	75.98	37.74	0.629
Al_2O_3	.33	.08	.19	.002
CaO	33.23	9.56	25.43	.454
MnO	.45	.24	.63	.009
Na_2O	9.11	1.84	4.89	.079
NH_3		2.23	5.93	.349
H_2O at 100	.27	1.18		
H_2O above 100	2.70	9.47	25.19	1.399
CO_2	.67			
	100.10	100.58	100.00	

These ratios roughly suggest the formation of a salt approximating in composition to the formula $R'_2Ca_2Si_3O_9.6H_2O$, in which R' is about two-thirds ammonium and one-third sodium. The large amount of water found was doubtless absorbed during the process of leaching. Pectolite itself has the formula $NaHCa_2Si_3O_9$, so that the existence of a hydrous ammonium pectolite is indicated; a conclusion which is probable but not proved. The reaction between pectolite and ammonium chloride is possibly simple at first, but followed by or entangled with secondary changes which obscure the results. The experiments are interesting, however, as showing how widely pectolite differs from the other minerals which we have studied, as regards the ammonium chloride reaction.

WOLLASTONITE.

The only data relative to the action of ammonium chloride upon wollastonite are those given in the original paper by Schneider and Clarke, but on account of the close relationship between this species and pectolite it seems desirable to reproduce the record here. The mineral studied was from Diana. N. Y., and it had the subjoined composition:

SiO_2	50.05
Al_2O_3,Fe_2O_3	1.13
CaO	47.10
Na_2O	undet.
MgO	.09
H_2O	.45
	98.82

After two heatings with ammonium chloride in an open crucible, 36.98 per cent of lime became soluble in water. In other words, a very notable decomposition had occurred, as in the case of pectolite. Since wollastonite is an anhydrous mineral, this result shows that the reaction does not depend upon the presence of hydroxyl.

APOPHYLLITE.

Upon this species only one rather crude experiment was made, and that with material of unknown locality. Heated with ammonium chloride in a sealed tube, it gave up, on leaching with water, 21.59 per cent of lime and 5.18 of potassa. The residue contained only 0.79 per cent of ammonia. Evidently the mineral, like pectolite and wollastonite, is largely decomposed by the reagent; but it is uncertain whether any regular ammonium compound is formed. It must be remembered that apophyllite sometimes contains small quantities of ammonia, and hence it seems that a more complete investigation of it *is desirable.*

DATOLITE.

The compact, porcelain-like datolite from Lake Superior. This was heated in a sealed tube with ammonium chloride in the usual way. After leaching the product with water, the washed residue contained 91.09 per cent of silica and 1.17 of ammonia. Evidently the datolite molecule had been thoroughly broken down, with nearly complete removal of the bases and the boric acid. The significance of the retained ammonia, however, is not clear.

ELÆOLITE.

On account of their interest as rock-forming minerals, the three species nephelite var. elæolite, sodalite, and cancrinite were studied consecutively and with some reference to one another. The elæolite was the characteristic material from the elæolite-syenite of Litchfield, Me., and had the following composition:

SiO_2	45.91
Al_2O_3	31.14
Fe_2O_3	.34
FeO	.23
CaO	.33
Na_2O	14.60
K_2O	5.60
H_2O at 100°	.47
H_2O above 100°	.93
CO_2	.40
	99.95

Five grams of mineral were thoroughly mixed with 20 grams of ammonium chloride by long grinding in an agate mortar, and then heated for six hours in a sealed tube to 350°. Even during the grinding a strong smell of ammonia was noticeable, and upon opening the sealed tube after heating, a slight pressure of ammonia gas was observed. On extraction with water the following bases passed into solution:

$Fe_2O_3.Al_2O_3$	0.29
CaO	.07
Alkalies (calculated as soda)	2.10

The residue from the leach water was dried at 50°, and then found to contain 0.92 per cent of ammonia. These figures confirm those obtained in a much less careful preliminary experiment, and show that elæolite is but slightly affected by the reagent.

CANCRINITE.

The material studied was the well-known bright yellow cancrinite from Litchfield, Me., and an analysis of it gave the following results:

SiO_2	36.19
Al_2O_3	29.24
Fe_2O_3	trace
CaO	4.72
Na_2O	19.20
K_2O	.14
H_2O	4.15
CO_2	6.11
	99.75

Upon boiling the powdered mineral for fifteen minutes with the standard solution of sodium carbonate, 0.55 per cent of silica went into solution. After ignition, only 0.32 per cent was soluble. No silica, therefore, had been split off by heating.

With ammonium chloride two experiments were made. In each case the mineral was intimately ground with four times its weight of the chloride, and heated to 350° in a sealed tube for four hours. During grinding a strong smell of ammonia was noticed, and still more was given off when the tubes were opened. The products were leached with water, and the thoroughly washed residues were analyzed, as follows:

	A.	B.
SiO_2	37.48	37.51
Al_2O_3	31.23	31.98
CaO	5.10	5.30
$Na_2O(+K_2O)$	7.78	7.53
NH_3	4.73	3.77
H_2O at 100°	1.29	14.48
H_2O above 100°	12.24	
CO_2	none	none
	99.85	100.57

In the wash water from product B, 11.73 per cent of the original soda was found, with no lime, and 0.16 per cent of silica and alumina. Somewhat less than two-thirds of the soda had been taken out. The lime seems to be much more stably combined, and water was taken up, probably in the process of leaching. The carbonic acid of the cancrinite had been completely eliminated.

Apparently, if the product of the reaction is a definite compound, the effect of the ammonium chloride has been to transform the cancrinite into a zeolitic body, approximating roughly to the general formula

$$R^1Al\ SiO_4.\ H_2O,$$

but with a small excess of the univalent bases. Analysis A, adjusted by rejecting the 1.29 per cent of hygroscopic water, and recalculation of the remainder to 100 per cent, assumes the following form and gives the appended ratios:

	Analysis reduced.	Ratios.
SiO_2	38.03	0.634
Al_2O_3	31.69	.311
CaO	5.17	.093
Na_2O	7.89	.127
NH_3	4.80	.282
H_2O	12.42	.690
	100.00	

The substance is evidently not absolutely pure, a condition which might have been expected. Any closer attempt at precise formulation would therefore be useless. It most nearly resembles, among the products which we have obtained, the ammonium derivative of thomsonite.

SODALITE.

Dark-blue sodalite from Kicking Horse Pass, British Columbia. Analysis as follows:

SiO_2	39.66
Al_2O_3	30.09
Fe_2O_3	.31
CaO	.18
Na_2O	22.60
K_2O	1.14
H_2O at 100°	.17
H_2O above 100°	.79
Cl	6.12
	101.06
Less O=Cl	1.39
	99.67

With ammonium chloride two preparations were made, both by the sealed-tube method at 350°. In A the heating lasted twenty-four hours; and in B six hours. From residue A, by leaching with water, 2.96 per cent of alkali, reckoned as soda, was extracted; and from B,

3.53 per cent. In the washed residues the following determinations were made, but complete analysis seemed to be unnecessary.

	A.	B.
SiO_2	39.33	40.00
$Al_2O_3(Fe_2O_3)$	31.40	32.34
CaO	.20	....
$Na_2O(K_2O)$	20.86	....
NH_3	.45	.72
Cl	5.92	....

Evidently the amount of change was slight, and no definite ammonium derivative had been formed.

In one way these results shed some light upon the constitution of sodalite. According to Lemberg and his pupils the mineral is a double salt, a molecular compound of sodium chloride with a silicate like nepheline. If this view were correct sodium and chlorine should be removed together by the action of a decomposing reagent. We find, however, that about 3 per cent of soda was removed from sodalite in forming residue A, while practically all of the chlorine remains behind. So far, then, the evidence is adverse to the view just cited and favorable to that of Brögger, which assigns the mineral, as an atomic compound, to a place in the garnet group.

On the other hand, sodium chloride may be volatilized from sodalite by prolonged heating. Two portions of the mineral were each heated for four hours over a blast-lamp flame, losing 10.80 and 10.72 per cent, respectively. The chlorine in the mineral, 6.12 per cent, corresponds to 10.08 per cent of NaCl; to this must be added the 0.91 of water found, making a total possible loss of 11.04 per cent. In the residue from the first lot ignited 0.20 of chlorine was found, so that the volatilization of sodium chloride had been almost complete. This reaction, however, taking place at a very high temperature, may be only a result of metathesis, and not by any means a proof that sodium chloride, as such, is an essential constituent of sodalite. The evidence derived from the ammonium chloride reaction is entitled to the greater weight.

THE FELDSPARS.

The results which we have obtained with these important rock-forming minerals are interesting only in so far as they show a trifling sensitiveness on the part of the several species toward dissociating ammonium chloride. The action upon them is slight, and ammonium derivatives do not seem to be formed. The data may be briefly summarized as follows:

Orthoclase.—From southeastern Pennsylvania, exact locality unknown. Quite pure cleavage masses. Heated for six hours with

ammonium chloride to 350° in a sealed tube, and leached with water, 1.52 per cent of KCl went into solution. The residue, dried at 50°, contained 0.20 per cent of ammonia.

Oligoclase.—The transparent variety from Bakersville, N. C. Treated like the orthoclase. In the leach water 0.96 per cent of lime and 2.71 of soda were found. The air-dried residue contained 1.47 per cent of ammonia. It is barely possible that in this case an ammonium derivative may have been produced, but the data are not positive enough to warrant any definite conclusion.

Albite.—Well-crystallized and very pure material from Amelia Courthouse, Va. Treated like the two preceding feldspars. Upon leaching, 0.12 per cent of lime and 0.84 of soda went into solution. In the residue, dried at 50°, 0.32 per cent of ammonia was retained.

OLIVINE.

Green, transparent pebbles from near Fort Wingate, N. Mex. Examined by Schneider and Clarke, who employed only the open crucible method. By treatment with ammonium chloride only 0.44 per cent of magnesia was rendered soluble in water—i. e., converted into magnesium chloride. In view of the ready solubility of this mineral in even weak aqueous acids, this lack of sensitiveness to ammonium chloride is somewhat remarkable.

ILVAITE.

This rare mineral was found by Mr. Waldemar Lindgren at the Golconda mine, South Mountain, Owyhee County, Idaho. It occurs in jet black masses and occasional rough crystals, embedded in quartz or calcite, and intimately associated with two other minerals which appear to be garnet and tremolite. Traces of pyrite also appear. The specific gravity of the ilvaite, as determined by Dr. Hillebrand, is 4.059 at 31°.

Upon grinding the powdered mineral with ammonium chloride in an agate mortar, a distinct smell of ammonia was noticeable. Three tubes of the mixture were heated to 350°, and one exploded because of the liberation of gas within. Upon opening the second and third tubes, a strong outrush of ammonia was observed. When the contents of these tubes were leached with water, large quantities of ferrous chloride went into solution, which, rapidly oxidizing, formed a deposit of brownish hydroxide, and interfered seriously with filtration. The greater part of the lime in the ilvaite was dissolved also. The washed residue, containing much ferric hydroxide, was partially analyzed, and enough data were obtained to show that a general breaking down of the ilvaite molecule had been effected. Apparently, also, small quantities of an ammonium derivative had been formed;

but this point is uncertain. The original mineral was analyzed by Dr. W. F. Hillebrand, and his analysis, contrasted with that of the leached residue, is here given:

	Ilvaite (Hillebrand).	Residue (Steiger).
SiO_2	29.16	43.01
Al_2O_3	.52	40.08
Fe_2O_3	20.40	
FeO	29.14	8.75
MnO	5.15	.85
CaO	13.02	2.25
MgO	.15	undet.
Na_2O	.08	undet.
NH_3		.88
H_2O at 105°	.15	undet.
H_2O above 105°	2.64	undet.
Cl		([a])
	100.41	95.82

[a] Small amount.

In the leached residue from the third tube 21.37 per cent of soluble silica was found—silica which had been liberated during the reaction between the ilvaite and the ammonium chloride. In short, ilvaite behaves toward the reagent much like pectolite, and the product is a mixture of uncertain character. The evident instability of the ilvaite molecule may account for its rarity as a mineral species. Only exceptional conditions would favor its formation.

RIEBECKITE(?).

The results obtained with ilvaite made it desirable to study, for comparison, some other silicates of iron. Among these the mineral from St. Peters Dome, near Pikes Peak, Colorado, originally described by Koenig as arfvedsonite, but identified by Lacroix as near riebeckite, happened to be available. It was treated with ammonium chloride in the usual way and no presence of liberated gas was noticed when the tube was opened. On leaching the product with water, ferrous chloride went into solution and ferric hydroxide with some manganic hydroxide was deposited. In the leached mass 6.90 per cent of soluble silica was found, and in the wash water from the leaching there was 6.76 per cent of soda. According to Koenig's analysis the mineral contains 8.33 per cent of soda, so that a large portion of the total amount had been extracted. There was also,

evidently, a considerable breaking down of the molecule, but no definite ammonium derivative had been formed. This is shown by the following analysis of the leached residue, which is contrasted with Koenig's published analysis[a] of the original mineral in order to indicate the amount of change. In the third column of figures we give the amount of each constituent which could be dissolved out from the residue by treatment with hydrochloric acid.

	Riebeckite (Koenig).	Residue (Steiger).	Soluble portion.
SiO_2	49.83	67.54	....
TiO_2	1.43	....	....
ZrO_2	.75	....	....
Fe_2O_3	14.87	21.28	15.74
FeO	18.86	4.94	4.94
MnO	1.75	.64	.64
MgO	.41	none	....
CaO	....	trace	....
Na_2O	8.33	1.04	....
K_2O	1.44		
NH_3	....	.53	.53
H_2O	.20	3.33	....
Cl	....	trace	....
	97.87	99.30	....

The residue is evidently a mixture of free silica and ferric hydrate with probably at least two silicates, one soluble, the other insoluble in hydrochloric acid. The reaction itself is noteworthy because of the fact that the original mineral is but slightly attacked when boiled with strong hydrochloric acid. The other minerals so far studied by us are all easily decomposable by acids, while this one is quite refractory. The energetic character of the ammonium chloride reaction is thus strongly emphasized.

ÆGIRITE.

Material from the well-known locality at Magnet Cove, Arkansas. Not absolutely pure, but somewhat contaminated by ferric hydroxide. This impurity is evident in a discussion of the ratios furnished by the analysis, but is not serious. It does not affect the problems under consideration. By heating with ammonium chloride the mineral was only slightly changed. In the leach water from the product there

[a] Dana's System of Mineralogy, 6th ed., p. 400.

were 1.66 per cent $(AlFe)_2O_3$, 0.51 CaO and 1.18 Na_2O. Analyses as follows: A of the ægirite, B of the air-dried, leached residue.

	A.	B.
SiO_2	50.45	51.83
Al_2O_3	2.76	25.24
Fe_2O_3	23.42	
FeO	5.26	5.69
MnO	.10	.....
MgO	1.48	1.58
CaO	5.92	5.74
Na_2O	9.84	9.07
K_2O	.24	
NH_3	.....	.26
H_2O at 100°	.15	.90
H_2O above 100°	.40	
	100.02	100.31

Of the silica in the residue 4.42 per cent was soluble in sodium carbonate solution. An ammonium derivative was not formed.

From these data we see that the three iron silicates are very differently attacked by ammonium chloride; ilvaite very strongly, riebeckite moderately, and ægirite but feebly. The ægirite is the most stable and at the same time the commonest of the three. A comparison of the ægirite analysis with that made by J. Lawrence Smith of material from the same region shows notable differences. The mineral evidently varies in composition, the variation depending upon the relative amounts of the two silicate molecules $FeNaSi_2O_6$ and $R''SiO_3$. Two samples taken from different parts of the same rock area are not necessarily identical in composition.

CALAMINE.

The simplest constitutional formula for calamine, the one which is generally accepted, represents it as a basic metasilicate,

$$SiO_3=(ZnOH)_2.$$

In this the hydrogen is all combined in one way, and so, too, is the zinc. In all other possible formulæ, simple or complex, the hydrogen as well as the zinc must be represented as present in at least two modes of combination; a condition of which, if it exists, some evidence should be attainable. Our experiments upon calamine have had this point in view; and we have sought to ascertain whether water or zinc could be split off in separately recognizable fractions. Our results, in the main, have been negative, and tend toward the support of the

usual formula; but the data are not conclusive, although they seem to be worthy of record.

The beautiful white calamine from Franklin, N. J., was selected for study, and gave the subjoined composition:

SiO_2	24.15
Al_2O_3, Fe_2O_3	.19
ZnO	67.55
CaO	.12
H_2O	7.95
	99.96

Fractional water.

At 100°	0.27
At 180°	.22
At 250°	.75
At 300°	.88
Incipient red heat	4.46
Full red heat	1.37
	7.95

Here no clear and definite fractionation of the water is recognizable, at least of such a character as to suggest any other than the ordinary formula for calamine.

Upon boiling powdered calamine with water, practically nothing went into solution, but by boiling with the solution of sodium carbonate 0.25 per cent of silica was dissolved. After ignition at a red heat, only 0.14 per cent of silica became soluble in sodium carbonate; and after blasting, only 0.24. In these experiments a very little zinc was dissolved also; but there was no evidence that any breaking up of the mineral into distinguishable fractions had occurred. In a hot 10 per cent solution of caustic soda both the fresh and the ignited calamine dissolve almost completely; but boiling with aqueous ammonia seems to leave the mineral practically unattacked. All experiments aiming to extract a definite fraction of zinc while leaving a similar fraction behind resulted negatively.

By heating with dry ammonium chloride in an open crucible, calamine is vigorously attacked and gains in weight by absorption of chlorine. In two experiments the mineral was intimately mixed with three times its weight of powdered sal ammoniac and heated in an air bath for several hours to a temperature somewhat over 400°. A large part of the residue was soluble in water, and the percentage of this portion, together with the percentage increase in weight, is given below:

	I.	II.
Gain in weight	27.60	25.78
Soluble in water	53.23	67.13

A conversion of calamine into the chlorhydrin $SiO_3(ZnCl)_2$ would involve a gain in weight of 15.34 per cent. Complete conversion into $2ZnCl_2+SiO_2$ implies an increase of 38.14 per cent. The figures given lie between these two, and are indefinite also for the reason that there was volatilization of zinc chloride.

In two more experiments the calamine, mingled with three times and four times its weight of ammonium chloride, respectively, was heated for an hour and a half to bright redness in a combustion tube. The zinc chloride which was formed volatilized and was collected by suitable means for determination. It corresponded to 59.6 and 59.0 per cent of the original mineral, calculated as zinc oxide, which indicates a nearly complete decomposition of the calamine into $2ZnCl_2+SiO_2$. The residue was mainly silica, with a small part of the zinc, about half of the silica being soluble in sodium carbonate solution. Here again no definite fractionation of the mineral could be observed.

Finally the action of dry hydrogen sulphide upon calamine was investigated. The mineral was heated to redness in a current of the gas and gained perceptibly in weight. The percentage data, reckoned on the original calamine, were as follows, in two experiments:

	I.	II.
Gain in weight	6.00	6.43
SiO_2 soluble in Na_2CO_3	16.45	20.95
Sulphur in residue	....	24.12

Complete conversion of calamine into $2ZnS+SiO_2$ implies a gain in weight of 5.80 per cent, and it is therefore evident from the figures of the second experiment that the limit of change was approached very nearly. The 24.12 of sulphur taken up is quite close to the 26.53 per cent which is required by theory. About eight-ninths of the calamine had undergone transformation. Again no definite fractionation was detected.

The hydrogen sulphide reaction was examined still further with reference to the temperature at which it becomes effective. Even in the cold calamine is slightly attacked by the gas, but its action is unimportant until the temperature of 400° is approximated. Then it becomes vigorous and the reaction goes on rapidly. A few experiments with willemite showed that it also was attacked by hydrogen sulphide, but less vigorously than calamine.

PYROPHYLLITE.

The empirical formula for pyrophyllite, $AlHSi_2O_6$, is apparently that of an acid metasilicate, and the mineral is therefore peculiarly available for fractional analysis. The compact variety from Deep

River, N. C., was taken for examination, and a uniform sample was prepared. Analysis gave the following results:

SiO_2	64.73
TiO_2	.73
Al_2O_3	29.16
Fe_2O_3	.49
MgO	trace
Ignition	5.35
	100.46

If, now, pyrophyllite is an acid metasilicate it should break up on ignition in accordance with the equation

$$2AlHSi_2O_6 = Al_2Si_3O_9 + SiO_2 + H_2O.$$

That is, one-fourth of the silica, or 16.18 per cent, should be liberated. The mineral itself is very slightly attacked by boiling with the sodium carbonate solution, and in an experiment of this kind only 0.72 per cent of silica was dissolved. Upon ignition under varying circumstances the following data were obtained:

Ignited ten minutes over a Bunsen burner, and then extracted with sodium carbonate solution, 1.51 per cent of SiO_2 dissolved.

Ignited fifteen minutes over a Bunsen burner, 1.89 per cent became soluble.

Ignited ten minutes over a Bunsen burner and then fifteen minutes over the blast, 2.84 per cent of silica was liberated.

These results are of a different order from those given by pectolite and talc, and raise the question whether pyrophyllite, despite its ratios, is a metasilicate at all. So far as the evidence goes, it may with propriety be regarded as a basic salt of the acid $H_2Si_2O_5$, and its formula then becomes

$$Si_2O_5 = Al - OH.$$

This formula is at least as probable as the metasilicate expression, which latter rests upon assumption alone. Still other formulæ, but of greater complexity, are possible; but until we know more of the genesis and chemical relationships of pyrophyllite, speculation concerning them would be unprofitable.

By heating with ammonium chloride in an open crucible pyrophyllite is very slightly attacked. In two experiments it lost in weight 6.17 and 6.30 per cent, respectively. The excess of loss over water is due, as we have proved, to the volatilization of a little ferric and aluminic chloride. The residue of the mineral after this treatment contained no chlorine, so that no chlorhydrin-like body had been formed. The formation of such a compound, the replacement of hydroxyl by chlorine, would, if it could be effected, be a valuable datum toward determining the actual constitution of the species. The sealed tube experiments were not attempted.

SERPENTINE.

In 1891 Clarke and Schneider published an investigation[a] relative to the action of gaseous hydrochloric acid upon various minerals. Among these were the three species, serpentine, leuchtenbergite, and phlogopite, and the remainders of the original samples were fortunately at our disposal. The analyses made by Schneider are therefore directly comparable with the new data secured by us.

The serpentine, from Newburyport, Mass., was but moderately attacked upon heating with ammonium chloride. Upon leaching the contents of the sealed tube with water, 0.18 per cent of silica and 5.23 of magnesia went into solution. The washed residue and the serpentine had the following composition:

	Serpentine (Schneider).	Residue (Steiger).
SiO_2	41.47	45.42
Fe_2O_3, Al_2O_3	1.73	.88
MgO	41.70	39.54
FeO	.09	-----
NH_3	-----	.09
H_2O	15.06	14.01
	100.05	99.94

The leached residue contained 1.06 per cent of soluble silica. The amount of change effected in the mineral was evidently small, and no ammonium compound was produced.

In Schneider and Clarke's[b] paper upon the ammonium chloride reaction a serpentine from the river Poldnewaja, district of Syssert, in the Urals, was studied. By a single treatment in an open crucible 4.93 per cent of magnesia became soluble in water as chloride. In a second experiment the mineral, after heating with 10 grams of ammonium chloride until volatilization ceased, was reheated with 10 grams more. Upon leaching, 14.30 per cent of magnesia went into solution. In a third trial the serpentine was thrice treated and only 10.63 per cent of magnesia was converted into chloride. In the last case the residue was boiled with sodium carbonate solution, which extracted 3.82 per cent of silica. The same serpentine was completely decomposable by aqueous hydrochloric acid, but only moderately attacked by the dry gas. The evident irregularity of these results is yet unexplained.

PHLOGOPITE.

From Burgess, Canada. The contents of the sealed tube, after heating, showed little appearance of change. The leach water contained magnesia. Analyses as follows:

[a] Bull. U. S. Geol. Survey No. 78, p. 11, 1891. [b] Bull. U. S. Geol. Survey No. 113, p. 34, 1893.

	Phlogopite (Schneider).	Residue (Steiger).
SiO_2	39.66	45.03
TiO_2	.56	----------
Al_2O_3	17.00	15.07
Fe_2O_3	.27	
FeO	.20	----------
BaO	.62	----------
MgO	26.49	24.94
Na_2O	.60	.94
K_2O	9.97	8.69
NH_3	----------	.21
H_2O	2.99	5.01
F	2.24	----------
	100.60	99.89
Less O	.94	
	99.66	

The residue, on boiling with sodium carbonate, gave 0.40 per cent of soluble silica. From these data it appears that phlogopite is somewhat attacked by ammonium chloride, but not strongly. No definite ammonium derivative is formed.

LEUCHTENBERGITE.

From the standard locality near Slatoust, in the Urals. When the contents of the sealed tube were leached with water, there passed into solution 0.19 per cent of alumina, plus iron, 2.10 of magnesia, and 2.03 of lime. The residue was not completely analyzed, but the few determinations made contrast with Schneider's results as follows:

	Leuchtenbergite.	Residue (Steiger).
SiO_2	32.27	32.82
Al_2O_3	16.05	----------
Fe_2O_3	4.26	----------
FeO	.28	----------
MgO	29.75	----------
CaO	6.21	4.67
NH_3	----------	.25
H_2O	11.47	12.11
	100.29	----------

No definite ammonium compound was formed, and the amount of decomposition was small. As the lime shown by the analysis is at least partly due to the presence of garnet as an impurity in the mineral, it will be interesting to determine the effect producible by ammonium chloride upon that species.

In Schneider and Clarke's investigation, conducted in open crucibles, this same leuchtenbergite, after three heatings with ammonium chloride, gave up 3.98 per cent of magnesia upon leaching with water. The residue contained a little magnesium oxychloride. With clinochlore from Slatoust similar results were obtained. A double heating with ammonium chloride extracted 2.12 per cent of magnesia, and a triple heating took out 3.80 per cent.

XANTHOPHYLLITE.

Variety waluewite, from the Nikolai-Maximilian mine, district of Slatoust, Urals. Examined by Schneider and Clarke, who found the mineral to be practically unattacked by gaseous hydrochloric acid, but completely decomposable by the aqueous acid. A triple treating with ammonium chloride in an open crucible took out 0.48 per cent of lime and 0.61 of magnesia. This amount of decomposition is insignificant.

THE ACTION OF AMMONIUM CHLORIDE ON ROCKS.

From the evidence so far presented it is clear that the ammonium-chloride reaction has much theoretical interest and that it adds a good deal to our knowledge of chemical constitution. But does it go any further than this and render any assistance in the elucidation of other problems? Consider, for instance, the rational analysis of silicate rocks—that is, the quantitative determination of certain mineral constituents as distinguished from the ordinary estimation of the oxides—is the reaction of any service here? We have found that among the rock-forming minerals analcite and leucite are completely transformable into ammonium salts, while elæolite and the feldspars are but little affected; olivine and the ferro-magnesian silicates also react but slightly. It would seem, therefore, as if analcite and leucite might be approximately determined by means of the reaction, the amount of change produced in a rock mixture being some measure of their quantity. To test this supposition, we have made a number of experiments, using for the purpose well-known rocks which had been studied both mineralogically and chemically.

Our method of procedure has been extremely simple, and no refinements of process have as yet been attempted. Each rock, in fine powder, was mixed with four times its weight of ammonium chloride and heated for several hours in a sealed tube to 350°. After cooling, the mixture was leached with water, and the amount of alkali passing into solution was estimated. From this soluble alkali the amount of analcite or leucite in the rock may be be roughly inferred, but of

course not with any great degree of accuracy. Still an approximate estimation is better than no measurement at all and is of service to the petrographer. Fortunately the errors of the process are to some extent compensatory; a little analcite or leucite will always escape transformation, while on the other hand a little alkali will always be yielded by other species. One error renders the estimation of the alkali too low, the other makes it high, but the two tend to balance each other. In the ordinary process for separating soluble from insoluble silicates by means of aqueous hydrochloric or very dilute nitric acid the same errors occur, but with additional complications due to the solution of magnesian minerals like olivine. Furthermore, aqueous acids will not discriminate between analcite and nepheline, two species which behave very differently toward dissociating ammonium chloride. So much premised, we may pass on to the description of our experiments.

First, we examined three rocks from the Leucite Hills, Wyoming, which were analyzed by Hillebrand and described by Cross.[a] Their mineralogical composition is as follows:

A. Orendite. Contains predominating leucite and sanidine, with phlogopite, a little biotite, diopside, and amphibole, and accessory apatite and rutile.

B. Wyomingite. Contains phlogopite, leucite, diopside, and apatite.

C. Madupite. Contains predominating diopside and phlogopite, with perofskite and magnetite, in a glassy base, which has approximately the composition of leucite.

On A and B duplicate determinations were made, but only one in the case of C. The substances extracted by leaching, after treatment with ammonium chloride, are given below:

	A 1.	A 2.	B 1.	B 2.	C.
Al_2O_3, Fe_2O_3	0.26	0.21	0.64	0.64	0.21
CaO	1.28	1.48	1.67	1.70	5.06
K_2O	4.68	4.53	9.50	9.38	6.81
Na_2O	.25	.43	1.33	1.35	1.08

The duplicates are fairly concordant. If now we regard the K_2O thus extracted as a measure of the leucite in each rock, giving the mineral its normal composition $KAlSi_2O_6$, we have the following percentages of the latter:

In orendite:	
1	21.81
2	21.11
In wyomingite:	
1	44.47
2	43.71
In madupite	31.73

[a] Am. Jour. Sci., 4th series, Vol. IV, p. 115. See also Bull. U. S. Geol. Survey No. 168, pp. 85 and 86, 1900, for analyses.

Two other leucite rocks were also studied by us, as follows, both being given in duplicate:

D. Missourite, Highwood Mountains, Montana. Described by Weed and Pirsson.[a] Analyzed by E. B. Hurlbut. Contains augite and leucite, with apatite, iron oxides, olivine, and biotite. Some zeolites and analcite are also present.

E. Leucitite. Bearpaw Mountains, Montana. Described by Weed and Pirsson.[b] Analyzed by H. N. Stokes. An olivine-free leucite basalt. Contains leucite, augite, iron oxides, rarely biotite, and a very small amount of glassy base.

The following substances were taken out by the ammonium chloride reaction:

	D 1.	D 2.	E 1.	E 2.
CaO	1.73	1.70	0.89	1.29
K_2O	4.09	3.74	6.19	6.16
Na_2O	.59	.64	1.44	1.47

Hence we have for leucite—

In missourite	19.06 and 17.43
In leucitite	28.84 and 28.70

It will be observed that the extracted soda is neglected in the computation. In missourite it may represent analcite; in the other rocks it perhaps belongs to a sodium equivalent of leucite, or it may come from some still different source. At all events, it serves to indicate some of the uncertainties attending the application of the method.

Among the rocks containing analcite as an essential constituent, only two were available for our purposes. They are:

F. Analcite-basalt, from Basin, Colorado. Described by Cross.[c] Analyzed by Hillebrand. Contains phenocrysts of augite, olivine, and analcite; also magnetite, and minor amounts of alkali feldspars, biotite, and apatite.

G. Heronite, from Heron Bay, Lake Superior. Described by Coleman.[d] Contains analcite, orthoclase, labradorite, aegirite, limonite, and calcite.

By treatment with ammonium chloride the following bases were extracted from these rocks, determinations being made in duplicate:

	F 1.	F 2.	G 1.	G 2.
CaO	1.74	2.28	1.64	1.62
K_2O	.46	.49	.21	.18
Na_2O	3.42	3.29	6.04	6.37

[a] Am. Jour. Sci., 4th series, Vol. II, p. 315; Bull. U. S. Geol. Survey No. 168, p. 133.
[b] Am. Jour. Sci., 4th series, Vol. II, p. 143; Bull. U. S. Geol. Survey No. 168, p. 136.
[c] See Bull. U. S. Geol. Survey No. 168, p. 146.
[d] Jour. Geology, Vol. VII, p. 431.

Hence, reckoning the soda as equivalent to normal analcite, $NaAlSi_2O_6.H_2O$, we have as percentages of the latter:

In analcite-basalt	26.33 and 25.33
In heronite	46.51 and 49.05

According to Coleman's computations, heronite contains 47 per cent of analcite. This figure agrees quite perfectly with our experimental determination.

In order to gain some notion of the extent to which other rocks, containing neither analcite nor leucite, might be affected by the reaction with ammonium chloride, four examples were chosen from among the many which have been studied in this laboratory.[a] They were:

H. Phonolite, Uvalde County, Tex. Contains sanidine, nepheline, and ægirite, with very little brown hornblende, augite, and magnetite.

I. Soda-granite-porphyry, Merced River, Mariposa County, Cal. Contains feldspar, largely albite, hornblende, muscovite, epidote, apatite, and iron ore.

J. Granitite, Placerville Canal, Eldorado County, Cal. Contains biotite, orthoclase, plagioclase, and quartz.

K. Augite-latite, Table Mountain, Tuolumne County, Cal. Contains labradorite, olivine, augite, and magnetite.

The bases extracted from these four rocks were as follows, in percentages:

	H.	I.	J.	K.
Al_2O_3, Fe_2O_3	0.33	0.19	0.58	....
CaO	.22	.29	none	0.66
K_2O	.41	.20	.20	1.21
Na_2O	4.38	.33	.23	.66

Among these rocks only the first one, the phonolite, was seriously affected; and it is difficult to account for the large amount of soda extracted. Neither nepheline nor ægirite taken alone gives up nearly so much soda as was liberated in this case, and no other sodium mineral has been reported present in the rock. In the other cases the amount of extraction is small and amounts to no more than the plus error, which was pointed out at the beginning of this discussion.

Taking all things into account, it seems probable that the analytical method proposed, although far from exact, is capable of some development, and is likely to yield results of some value. Perhaps it might be improved by taking into account the quantities of ammonia retained by the washed residues. From that source one estimate could be derived, and from the alkali in solution another; the two should give better information than either determination alone. But the precision of ordinary analytical processes is not to be expected here, and only useful approximations can be anticipated.

[a] For additional data and the analyses, see Bull. U. S. Geol. Survey No. 168, pp. 62, 199, 205, 207.

SUMMARY.

In the foregoing pages we have considered the action of ammonium chloride, at its temperature of dissociation, upon 31 mineral species. We have shown that its influence upon various silicates differs very widely, but that in general it is a much more powerful reagent than has been generally supposed. The results, in brief, are as follows:

First. Analcite, leucite, natrolite, and scolecite, heated with dry ammonium chloride to 350° in a sealed tube, yield alkaline chlorides and an ammonium aluminum silicate, which is stable at 300°. The reaction is simply one of double decomposition, the sodium or potassium of the original silicate being completely replaced by ammonium. Analcite and leucite give the same product, $NH_4AlSi_2O_6$. Natrolite and scolecite yield the salt $(NH_4)_2Al_2Si_3O_{10}$. The latter compound is a derivative of orthotrisilicic acid, $H_8Si_3O_{10}$; and in a separate section of the memoir its constitution and its relations to other trisilicic acids are considered.

Second. A similar reaction, a double decomposition, takes place incompletely with stilbite, heulandite, chabazite, thomsonite, laumontite, and pollucite. Part of the monoxide base is removed and replaced by ammonium, without change of atomic ratios. Cancrinite is also vigorously attacked, and partially transformed into a zeolitic body.

Third. Pectolite, wollastonite, apophyllite, datolite, ilvaite, and calamine are violently acted upon by ammonium chloride, and their molecules seem to be almost completely broken down. The products of the reactions are mixtures, and no ammonium silicates are formed.

Fourth. Elæolite, sodalite, riebeckite, olivine, serpentine, phlogopite, prehnite, orthoclase, albite, oligoclase, ægirite, pyrophyllite, leuchtenbergite, and xanthophyllite are but slightly attacked by dissociating ammonium chloride.

In the closing section of the work we have shown that the ammonium chloride reaction may be applied to an approximate quantitative determination of analcite and leucite in rocks, thereby aiding somewhat in the estimation of their mineralogical composition.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 207.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Bulletins, Professional Papers, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, Methods of hydrographic investigation; N, Water power; O, Underground waters; P, Hydrographic progress reports. This bulletin is the thirty-sixth in Series E, the complete list of which follows (all are bulletins thus far):

SERIES E, CHEMISTRY AND PHYSICS.

9. Report of work done in the Washington laboratory during the fiscal year 1883-84, by F. W. Clarke and T. M. Chatard. 1884. 40 pp.

14. Electrical and magnetic properties of the iron carburets, by Carl Barus and Vincent Strouhal. 1885. 238 pp.

27. Report of work done in the Division of Chemistry and Physics, mainly during the year 1884-85. 1886. 80 pp.

32. Lists and analyses of the mineral springs of the United States (a preliminary study), by Albert C. Peale. 1886. 235 pp.

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60. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1887-88. 1890. 174 pp.

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114. Earthquakes in California in 1893, by Charles D. Perrine. 1894. 23 pp.

125. The constitution of the silicates, by Frank Wigglesworth Clarke. 1895. 100 pp.

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147. Earthquakes in California in 1895, by Charles D. Perrine. 1896. 23 pp.

148. Analyses of rocks, with a chapter on analytical methods, laboratory of the United States Geological Survey, 1880 to 1896, by F. W. Clarke and W. F. Hillebrand. 1897. 306 pp.

155. Earthquakes in California in 1896 and 1897, by Charles D. Perrine. 1898. 47 pp.

161. Earthquakes in California in 1898, by Charles D. Perrine. 1899. 31 pp., 1 pl.

167. Contributions to chemistry and mineralogy from the laboratory of the United States Geological Survey; Frank W. Clarke, Chief Chemist. 1900. 166 pp.

168. Analyses of rocks, laboratory of the United States Geological Survey, 1880 to 1899, tabulated by F. W. Clarke. 1900. 308 pp.

176. Some principles and methods of rock analysis, by W. F. Hillebrand. 1900. 114 pp.

186. On pyrite and marcasite, by H. N. Stokes. 1900. 50 pp.

207. The action of ammonium chloride upon silicates, by F. W. Clarke and George Steiger. 1902. 57 pp.

Correspondence should be addressed to—

The DIRECTOR,

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WASHINGTON, D. C.

November, 1902.

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Bulletin No. 208 Series B, Descriptive Geology, 27

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

DESCRIPTIVE GEOLOGY

OF

NEVADA SOUTH OF THE FORTIETH PARALLEL AND ADJACENT PORTIONS OF CALIFORNIA

BY

JOSIAH EDWARD SPURR

WASHINGTON
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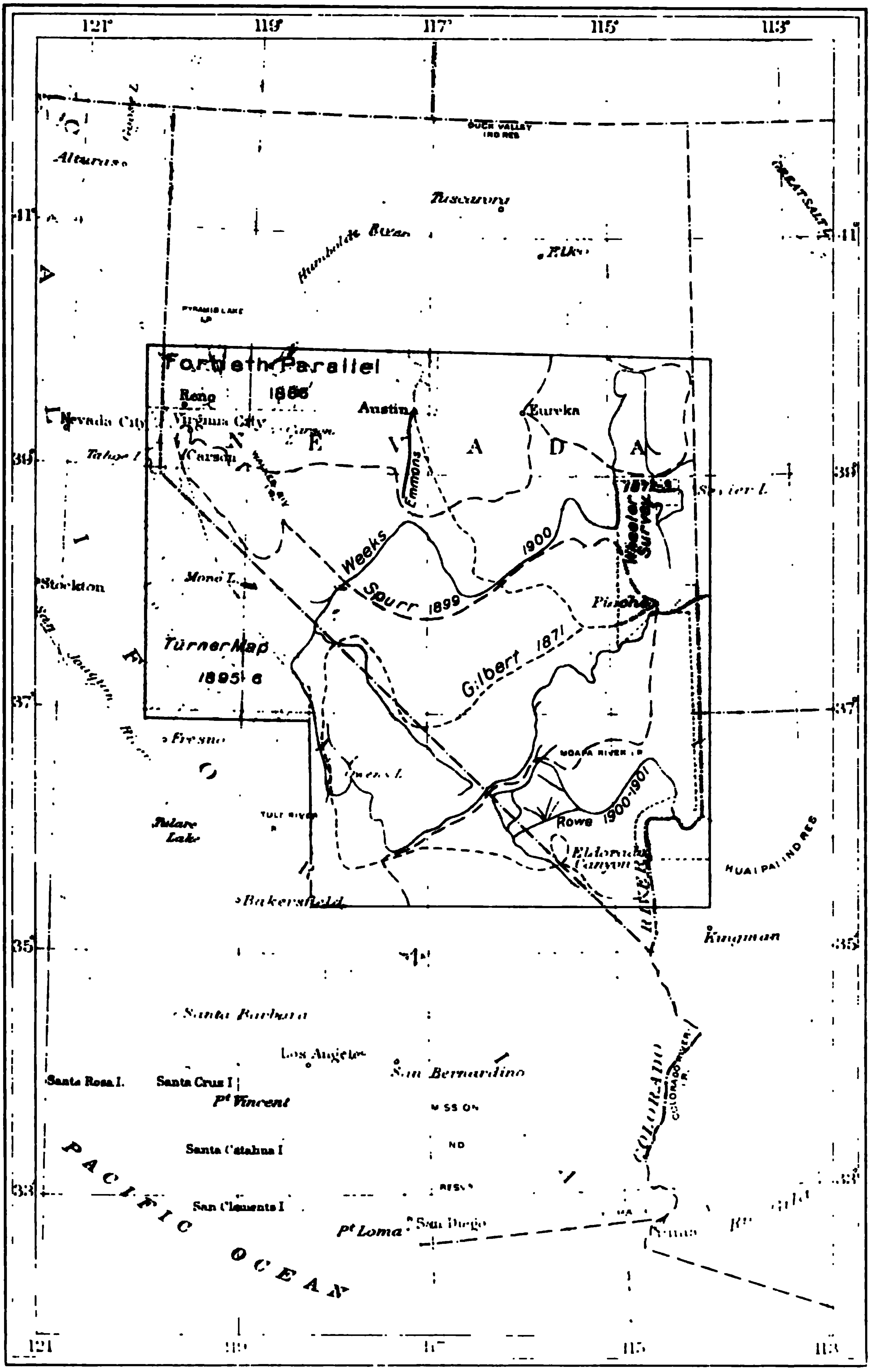
ILLUSTRATIONS.



MAP SHOWING POSITION OF

GEOLOGICAL RECONNAISSANCE MAP

AND CHIEF DATA USED IN ITS COMPILATION

DESCRIPTIVE GEOLOGY OF NEVADA SOUTH OF THE FORTIETH PARALLEL AND ADJACENT PORTIONS OF CALIFORNIA.

By JOSIAH EDWARD SPURR.

INTRODUCTION.

The field work upon which the present bulletin is based, so far as the writer's labors are concerned, was done in the summer and fall of 1899. After visiting the Wasatch Range to study briefly the Wasatch Paleozoic section, as determined by the Fortieth Parallel Survey, the writer proceeded to Eureka, in Nevada, and there spent two weeks in studying that section, the best and most complete yet discovered in the far West. Feeling finally ready for untried ground, the expedition, consisting, besides the writer, of a teamster, a cook, and an assistant, left Eureka and proceeded southeastward to Hamilton, and then to Ely. From Ely the route ran to Osceola in the Snake Creek Range, thence across that range and northward up Snake Valley to Pleasant Valley, where a westward course was again taken. Schellbourne and Cherry Creek, the latter in the Egan Range, were next visited, and thence the way led northwestward to Ruby Lake, and so back to Eureka. During part of this journey some of the region which had been mapped by the Fortieth Parallel Survey was traversed, this route being purposely chosen so as to permit study in the field of the application of the Fortieth Parallel geologic section. After replenishing supplies at Eureka the expedition took the road southward to Hot Creek, and thence proceeded westward to Belmont. The country to Carson was then traversed, the more or less inactive mining camps of Ione, Ellsworth, and Downieville and the Indian reservation at Walker Lake being passed. At Carson a short time was spent, and the famous Comstock lode and the southern end of the Virginia Range were visited. From Carson the route was southwestward past Wellington, Hawthorne, Sodaville, Columbus, and Silver Peak, to Lida. From Lida the course was again toward the east, and the State of Nevada was crossed again by way of the Ralston Desert, Twin Springs, and White River, to Pioche. From Pioche, Meadow Valley Canyon was followed southward to the Indian reservation at Moapa or West Point, not far from the Colorado, then, a turn to the west being made, the

State was crossed a third time, by way of Indian Springs and Pahrump Valley, into California. Funeral Range was crossed and Death Valley entered at Furnace Creek. From here the expedition went southward, and, crossing the Panamint Range at Windy Gap, proceeded by way of Granite Wells to Johannesburg. From Johannesburg the party proceeded across the Mohave Desert, crossing the Santa Fe Railroad at Hinckley. Finally San Bernardino was reached, which was the end of the journey. This trip lasted about five months, and comprised over 2,000 miles of actual travel.

The primary object of the expedition was to make the roughest kind of a general geologic map, such as might fill up the great gaps in the map of the western United States. It being the intention of the Survey to publish a general geologic map of the United States on a scale of about 40 miles to the inch, no great amount of detail was advisable or possible. On account, also, of the rough and inaccurate manner in which much of the region of the western United States has been already mapped, it was not advisable to undertake to do any work of higher grade.

In order to accomplish the style of mapping desired with as much economy of time and labor as possible, the writer determined to avoid any duplication between his route and those already traveled by geologists, and carefully planned his journeys with that end in view. On the north the area which he undertook to investigate was bounded by the geologic maps of the Fortieth Parallel Survey (atlas maps 4 and 5); on the east it was bounded by the geologic maps of the Wheeler survey; and on the west chiefly by a reconnaissance map of the Sierra Nevada published by Mr. H. W. Turner in the Seventeenth Annual Report of the United States Geological Survey, Part I; on the south there was no definite boundary.

Within the area to be mapped, about the only important journey that had been made by a geologist had been accomplished by Mr. Gilbert in 1871, while with the Wheeler Topographic Survey. His route, with the other boundaries already mentioned, is shown on Pl. II. The writer was able to so plan his route with reference to the work of Mr. Gilbert and to the maps which bounded the area that hardly any point in the region examined can be found which is more than 30 miles from a point of observation. This in any country would probably be sufficient for a reconnaissance map on a scale of 40 miles to the inch, but in the Great Basin region of Nevada and California the conditions are especially favorable, so that a map can be made having far more value than in ordinary regions. The clear air, the lack of vegetation, and the general continuity of formations parallel with the north-south ranges all combine to make a reconnaissance more satisfactory than usual. The attitude of strata or a conspicuous formation may often be followed 15 or 20 miles along the front of a mountain, by the aid of a field glass, from a single point.

The foregoing explanation indicates clearly enough the character of the map and the weight which should be placed upon it. The data along the lines of reconnaissance, often obtained on forced marches of 20 or 30 miles a day, are oftentimes meager and unsatisfactory. Between the lines of actual travel the data are still less reliable, and a great deal of the mapping has been done simply from inference. Thus it is probable that anyone examining closely the detail of the map will find it nearly all inaccurate, while one looking for the main principles will recognize the general correctness of the mapping and the value of the map as a pioneer.

The inaccuracy of the map is unavoidably heightened by the lack of a suitable topographic base. The present base has been prepared in a very rough and unsatisfactory way, chiefly from the Wheeler and other early surveys. It is a source of regret to the author of the bulletin that so rough a topographic map must be presented as the vehicle for his geologic information.

Within the text of the bulletin an effort has been made to give clearly the known facts concerning the geology, whether obtained by the writer or previously. Full credit is given to previous work, although it can not always be given in the map compiled from this information. The chief sources, however, are shown on Pl. II.[a]

The writer has judged it most advisable to confine the text to descriptive matter. General results, especially those involving application of theory, have been withheld or published separately. Among these general results the author has published two papers on volcanism in the Journal of Geology, entitled The Succession and Relation of Lavas of the Great Basin Region (October-November, 1900), and Transitions of Texture in certain Tertiary Igneous Rocks of the Great Basin. A petrographic paper on Quartz-muscovite Rock from Belmont, Nev., has been published in the American Journal of Science (November, 1900). A paper on the Origin and Structure of the Basin Ranges was read before the Geological Society of America at Albany, December, 1900.

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[a] After the above was written, and while the bulletin was in galley proof, new information was received as a result of the studies of Messrs. Weeks and Rowe, of the U. S. Geological Survey. The studies of Mr. Weeks were made in 1900; those of Mr. Rowe in 1900 and 1901. The results of these have been incorporated in the bulletin.

EXPLANATION OF FORMATION NAMES.

The following is a brief explanation of formation names used in this work. Names are arranged alphabetically.

Aubrey limestone and sandstone.—These names were applied by Messrs. Gilbert and Marvine in 1871 to formations in the Colorado Canyon region. The limestone lies above the sandstone and has a thickness of 820 feet on Kanab Creek. At a few points in the topmost layer were found a group of shells suggesting the Permo-Carboniferous of the Mississippi Valley, indicating that the great Paleozoic lithologic change at this horizon marks the absolute close of the Carboniferous age. Lithologically the limestone is characterized by a great abundance of chert, which toward the top sometimes constitutes half the mass. Near the middle it is in some places interrupted by a belt of shale with gypsum.

The underlying Aubrey sandstone series has a thickness in the Aubrey cliffs and along the Grand Canyon of about 1,000 feet. In every exposure a portion of this body is massive and cross bedded and another portion soft and gypsiferous, but the order of these parts is not constant. The sandstones contain no fossils, but an intercalated limestone below the middle of the series at Canyon Creek bears familiar Coal Measures shells.[a]

Chuar series.—This name was introduced by Mr. C. D. Walcott in 1883 for a part of the Lower Cambrian of the Grand Canyon region. Mr. Walcott divided the Grand Canyon group of Major Powell into a lower and an upper division, the Grand Canyon and the Chuar. In 1886 the reference to the Lower Cambrian was changed to pre-Cambrian. In 1890 these strata were referred to the Algonkian system. In 1894 Mr. Walcott again classified the Algonkian, dividing the Grand Canyon series of this system into the upper (Chuar) series and the lower (Unkar) series. The Chuar is separated by an unconformity from the overlying Cambrian (Tonto series).[b]

Diamond Peak quartzite.—This name was given by Mr. Hague to the lowest lithologic member of the Carboniferous at Eureka, Nev. At this place the Diamond Peak quartzite consists of 3,000 feet of massive gray and brown quartzites, with brown and green shales at the summit. It underlies 3,800 feet of heavy bedded, dark-blue and gray,

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 177.
[b] Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, p. 506.

Lower Coal Measures limestone, which contains intercalated beds of chert and argillaceous beds near the base. The Diamond Peak quartzite is not a persistent lithologic terrane, and is not recognizable with confidence at any great distance from the Eureka section.

Esmeralda formation.—This name was applied by Mr. H. W. Turner[a] to Tertiary formations in the Silver Peak Range, in the western part of Nevada. These deposits consist of sandstones, shales, volcanic tuffs, breccias, conglomerates, and great thicknesses of lacustrine marls. Coal beds and plant remains occur; also fossil shells and fish bones. From the evidence afforded by these fossils, the age of the beds was broadly determined as late Eocene or early Miocene.

Eureka quartzite.—This name was applied by Mr. Hague to the middle of the three divisions of the Silurian in the Eureka district. This division here consists of 500 feet of compact vitreous quartzite, white or blue in color, and passing into rock of reddish tints near the base, with indistinct bedding. It overlies the Pogonip limestone, and is separated from the overlying Silurian Lone Mountain limestone by an unconformity. The Eureka quartzite appears to be one of the most persistent lithologic terranes of the Nevada Paleozoic. It has been recognized over a wide area.

Grand Canyon group.—The name Grand Canyon group was given by Maj. J. W. Powell to the strata in the Grand Canyon region beneath the Tonto sandstone and above the Grand Canyon schists. The latter were referred tentatively to the Eozoic, and the 10,000 feet of the Grand Canyon group to the Silurian. In 1883 Mr. C. D. Walcott referred Major Powell's Grand Canyon group to the Lower Cambrian and separated it into an upper and a lower division, the Grand Canyon and the Chuar. In 1886 these rocks were referred by Mr. Walcott to the pre-Cambrian, and in 1890 to the Algonkian. In 1894 Mr. Walcott subdivided the Grand Canyon group of the Algonkian into the Chuar and the Unkar series. The Grand Canyon group is separated by an unconformity from the overlying Cambrian (Tonto sandstone), and by a great unconformity from the underlying Vishnu series of schists.

Hamburg limestone and shale.—The Hamburg limestone and shale are the uppermost divisions of the Cambrian as defined by Mr. Hague in the Eureka district, Nevada. The Hamburg shale lies at the very top and consists of 350 feet of yellow argillaceous shale containing layers of chert nodules, especially near the top. The underlying Hamburg limestone consists of 1,200 feet of dark-gray granular limestone, with only slight traces of bedding. The Hamburg shale is characterized by well-developed Upper Cambrian fauna.[b]

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[a] Am. Geol., Vol. XXV, p. 168.

[b] Second Ann. Rept. U. S. Geol. Survey, p. 27; Third Ann. Rept., p. 255.

Humboldt series.—This name was applied by King[a] to a series of loose, friable Tertiary rocks, carrying very recent fresh-water mollusks. This series is found at intervals all over the northern portion of the Great Basin region, from the Sierra Nevada into Utah. Mr. King regarded all these beds, which from their fossils were referred to the late Pliocene, as lake deposits and as representing the sediment of a single lake out of which the numerous lofty mountain masses rose in a complicated system of islands.

Koipato formation.—This name was applied by Mr. King[b] to one of the two chief divisions of the Triassic in western Nevada. He describes the Koipato as made up of siliceous and argillaceous beds, whose chemical peculiarity is the almost total absence of soda and lime and the high percentage of alumina and potash. This series has an observable thickness of about 6,000 feet, with an unknown quantity to be added for the unseen beds at the bottom. The Koipato is overlain by the Triassic Star Peak series.

Lone Mountain limestone.—This name was given by Mr. Hague to the uppermost division of the Silurian in the Eureka district. It consists of 1,800 feet of strata. At the base are black gritty beds passing into light-gray siliceous rocks with all traces of bedding obliterated. There are Trenton fossils at the base and *Halysites* in the upper portion. The formation is separated from the underlying Silurian Eureka quartzite by an unconformity, and is overlain conformably by the Devonian Nevada limestone.

Nevada limestone.—The Nevada limestone, as defined by Mr. Hague,[c] is the lower member of the Devonian series at Eureka. It consists of 6,000 feet of limestone. The lower horizons are indistinctly bedded, with saccharoidal texture and gray color, passing up into distinctly bedded strata, reddish brown and gray in color, frequently finely striped, producing a variegated appearance. The upper horizons are massive, well bedded, bluish black in color, and highly fossiliferous. The Nevada limestone overlies the Silurian Lone Mountain limestone at Eureka and is overlain by the Devonian White Pine shale.

Ogden quartzite.—This term was applied by King[d] to a sheet of siliceous sediment, in general compacted into a quartzite. Mr. King stated that this formation had a remarkable evenness over all the Paleozoic area west of and including the Wasatch. In its typical locality, Ogden Canyon, Wasatch Range, it was stated to be 1,200 or 1,400 feet thick; at Cottonwood Canyon 1,000 feet, and in middle Nevada from 800 to 900 feet. In Ogden Canyon it is bounded at the top and bottom by thin beds of greenish-gray argillites; and

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[a] U. S. Geol. Expl Fortieth Par., Vol. I, p. 434.
[b] Ibid., p. 346.
[c] Third Ann. Rept. U. S. Geol. Survey, p. 255.
[d] Op. cit., p. 234.

about the middle of the quartzite is a thin bed of white, slightly siliceous marble. No fossils were found in this formation, but it was referred to the Devonian, since it was found to overlie the Pogonip limestone, which contains Lower Helderberg fossils, and is overlain by the Wasatch limestone, whose basal beds contain Upper Helderberg forms.

Pogonip formation.—King[a] described the Pogonip limestone in middle Nevada, in the regions of White Pine, Eureka, Pinyon, and Roberts Peak ranges, as being Cambrian in the lower half and containing Silurian fossils in its upper 2,000 feet. In the Eureka section, the term Pogonip was limited by Mr. Hague[b] to the Silurian portion of the series, which consists of 2,700 feet of interstratified limestone and argillites, with arenaceous beds at the base. These rocks pass into pure, fine-grained limestone of a bluish-gray color, distinctly bedded. They are highly fossiliferous. The Pogonip limestone is the lowest member of the Silurian of the Eureka section. It overlies the topmost member of the Cambrian, the Hamburg shale, conformably, and is conformably overlain by the Silurian Eureka quartzite.

Prospect Mountain limestone and quartzite.—These names were given by Mr. Hague[b] to the two lowest divisions of the Cambrian section at Eureka, Nev. The Prospect Mountain quartzite is the lowest and consists of 1,500 feet of bedded brownish-white quartzites, weathering dark brown but whiter near the summit. The quartzites contain intercalated thin layers of arenaceous shales, and are ferruginous near the base.

The quartzite is overlain by the Prospect Mountain limestone, which consists of 3,050 feet of gray, compact limestone of rather light shade, traversed by thin seams of calcite. It has very imperfect bedding planes. The upper portion of the Prospect Mountain quartzites is characterized by the *Olenellus* or Lower Cambrian fauna, and the Prospect Mountain limestone by the Middle Cambrian fauna of the Rocky Mountain section.

Red Wall limestone.—This name was applied by Messrs. Gilbert and Marvine[c] to a heavy Carboniferous limestone in the Grand Canyon region. This limestone has a gray color on fresh fracture, but shows a red rust on weather-stained cliffs. It is generally heavy bedded to massive. At the top sandstone alternates with limestone for from 200 to 500 feet. Through its lower half the limestone is interrupted by occasional shaly bands. The average total thickness is 2,500 feet. Fossils are abundant near the top but rare in the lower part. The upper portion contains Coal Measures fossils. The lowest

[a] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 232.
[b] Third Ann. Rept. U. S. Geol. Survey, p. 255.
[c] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 178.

fossils were obtained just below the middle of the series, and were doubtfully referred to the Lower Carboniferous.

Secret Canyon shale.—This name was applied by Mr. Hague[a] to a division of the Cambrian in the Eureka district overlying the Prospect Mountain limestone and underlying the Hamburg limestone. It consists of 1,600 feet of yellow and gray argillaceous shales, passing into shaly limestone. This formation is characterized by a fauna that may be referred to the upper portion of the Middle Cambrian.

Star Peak formation.—This name was applied by Mr. King[b] to the uppermost of the two great divisions of the Triassic of western Nevada. The series consists of 10,000 feet of strata, made up of an alternation of three great limestone zones and three interposed quartzite zones. The upper two quartzites represent moderately pure siliceous sediment, while the lower quartzite closely follows the physical and chemical peculiarities of the underlying Triassic Koipato series. The fossils of these limestones are marvelously like the St. Cassian and Hallstadt of the Austrian Alps. Directly overlying the uppermost Star Peak quartzite is a limestone carrying Lower Jurassic or Liassic forms, and succeeded upward by an immense series of argillites of unknown thickness.

Tonto shale and sandstone.—The name Tonto was applied by Mr. G. K. Gilbert[c] in 1874 to a series of sandstones and shales lying between the subjacent granite and the superjacent limestones which occur at the mouth of the Grand Canyon in Arizona. He considers the formation of Primordial age, and it has been since found to contain an Upper Cambrian fauna.[d]

Truckee formation.—Mr. King[e] proposed the name Pah-Ute Lake for a fresh-water Miocene lake, which is regarded as extending from the region of the Columbia River, and perhaps still farther north, far south through Oregon and Nevada into California. To the beds of this lake in the fortieth parallel area he gave the name of Truckee Miocene. They are made up of 150 feet or less of detrital rocks and gritty sandstones, with some conglomerate. Above these lie about 250 feet of palagonite tuff. Above this is 250 to 300 feet and more of infusorial silica, followed by 120 feet of detrital sandy rocks, containing also infusorial silica. Above these comes 60 feet of fresh-water limestone, which is succeeded upward by 250 feet of detrital grits; and the latter give away to an enormous formation of volcanic tuffs. In Nevada the thickness of these volcanic muds is 2,000 or 3,000 feet; in Oregon it is even more.

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[a] Third Ann. Rept. U. S. Geol. Survey, p. 255.
[b] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 346.
[c] Bull. Washington Philos. Soc., Vol. I, p. 109.
[d] C. D. Walcott, Bull. U. S. Geol. Survey No. 81, p. 245.
[e] Op. cit., p. 454.

Unkar formation.—This has already been mentioned, under the headings Grand Canyon and Chuar, as the lowest division of the Grand Canyon group of the Algonkian in the Grand Canyon section. It is overlain conformably by the Chuar, and separated below by a great unconformity from the Vishnu series.

Wasatch limestone.—The term was applied by King[a] to an enormous body of limestone seen in the Wasatch and farther west, but not to the east. He describes it as a single body of limestone about 7,000 feet in thickness, holding its enormous volume with remarkable evenness wherever observed over Utah and Nevada. It is underlain by the Ogden quartzite, from which it is lithologically sharply distinguished. Above, it passes into the great Weber quartzite, but there is an alternation of sandstone and limestone beds at this transition and the thickness of these intercalated beds is very variable, reaching sometimes about 1,000 feet.

The lower 1,400 feet of the Wasatch limestone was regarded as Devonian. Above this is 300 or 400 feet of dark, heavy limestones carrying fossils resembling those of the Waverly group, but which perhaps are closer to the Devonian. Directly above these are 400 or 500 feet of dark beds carrying Lower Carboniferous fauna, and above these the upper 4,500 feet of the limestone is characterized by abundant Coal Measures fossils.

The term Wasatch was not retained in the Eureka section,[b] the Devonian and Carboniferous being subdivided into various formations. However, these lithologic subdivisions are not readily recognizable at many other points in Nevada, and the old term is often convenient.

Weber conglomerate.—Mr. King[c] described the Weber quartzite as a body of indurated sandstone and quartzite carrying occasional sheets of conglomerate, interposed between two bodies of Coal Measures limestone. He described it as obtaining a thickness of 2,000 feet in the Wasatch, 8,000 feet in the Oquirrh, and probably more in middle California. This formation overlies the Wasatch limestone and underlies the Upper Coal Measures limestone.

The same formation was recognized by Mr. Hague[d] at Eureka, where it is underlain by the Lower Coal Measures limestone and overlain by the Upper Coal Measures limestone. Its thickness at Eureka, however, is only 2,000 feet. Here it consists of coarse and fine conglomerates, with angular fragments of chert and layers of reddish-yellow sandstone.

White Pine shale.—This term was applied by Mr. Hague[d] to the

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[a] U. S. Geol. Expl. Fortieth Par., Vol I, pp. 235-239.

[b] Arnold Hague, Mon. U. S. Geol. Survey, Vol. XX, p. 13.

[c] Op. cit., p. 240.

[d] Loc. cit.

uppermost of the lithologic divisions of the Devonian in the Eureka district. It consists of 2,000 feet of black argillaceous shales, more or less arenaceous, with intercalations of red and reddish-brown friable sandstone, changing rapidly with the locality. The beds contain plant impressions. The formation is underlain by the Devonian Nevada limestone and overlain by the Carboniferous Diamond Peak quartzite. These lithologic subdivisions seem to change rapidly as one goes away from the Eureka district, and have not often been certainly identified.

CHAPTER I.

RANGES OF EAST-CENTRAL NEVADA.

SNAKE RANGE.

The Snake Range lies next east of the Schell Creek Range and for the most part just west of the Nevada-Utah line. It is the most conspicuous range between the Wasatch and the Humboldt. The northern end of the range has been variously called the Deep Creek Mountains or the Ibenpah Mountains, while just south of this part of the range a transverse ridge has been called the Kern Mountains; but here they will all be included under the general name Snake Range. The range, as thus defined, extends from about latitude 40° 15′ about 135 miles in a direction a little west of south. At its southern end it runs into a group of irregular mountains, probably in large part volcanic, of which certain portions go by the name of the Cedar Mountains, and the Piñon Mountains of Lincoln County.

TOPOGRAPHY.

The relief of the Snake Range is in general great. The mountains are divided into irregular ridges which are broken and separated by transverse east-west gaps. By two such gaps the so-called Kern Mountains are separated from the rest of the range, and a similar but lower gap occurs just north of Wheeler or Jeff Davis Peak. This peak has the highest elevation of any between the Sierra Nevada and the Wasatch, attaining over 12,000 feet (Pl. III, *A*). Directly south of this the mountains decrease rapidly in height and pass into the low volcanic peaks above mentioned.

Some of the erosion forms are interesting. On the east side of the range, between Wheeler Peak and the Kern Mountains, a number of springs furnish continual streams. At the mouths of the gulches from which such streams flow the Pleistocene wash which covers the base of the mountains has been lowered fully 500 feet below the wash on both sides, and the stream flows through this deposit between steep banks 40 feet high. Where near-by gulches which do not contain any continual streams join the same detrital apron, the reverse is the case, the gulches being fronted by huge alluvial fans higher than the rest of the plateau.

Considering the gulches formed by these continual streams and comparing them with the neighboring gulches which do not contain springs, we find a strong contrast. Smith Creek, for example, is

a spring flowing in the bottom of a magnificent narrow canyon, bounded by perpendicular walls 2,000 or 2,500 feet high. In these walls are a number of large holes or caves in the limestones, which evidently represent the former courses of the same spring that now emerges in the gulch bottom. From the distribution of these caves it appears that the spring has been flowing during all the time that the canyon has been eroding and that its former underground courses have been exposed by the down cutting. The adjacent gulches, which do not continually contain running water, have V-shaped valleys without box canyons, and are much shallower.

In this canyon are small working mines.

ARCHEAN ROCKS.

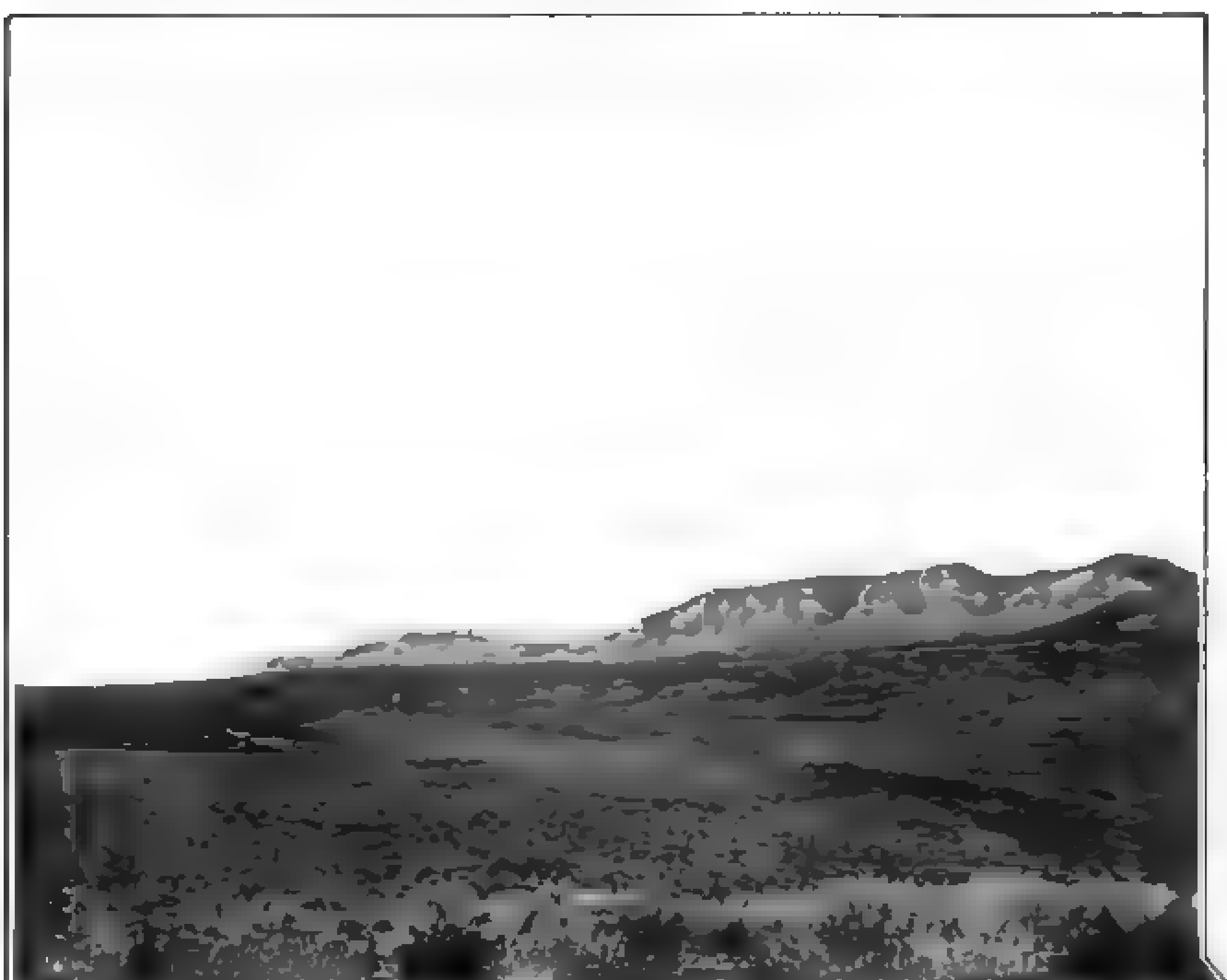
Howell found fragments of granite in the wash which came down from Wheeler Peak, and regarded this as Archean, underlying the undoubtedly Cambrian quartzite. Farther north, on the east face of the mountain, and on the north side of the gap which runs transversely across the range north of Wheeler Peak, the writer found abundant schistose granite in the drift and in one locality in place. Where it was found in place it seemed to lie beneath limestones which are probably Cambrian, with no intervening quartzite. Farther north, also on the eastern side of the range, one finds continually huge blocks of schistose granite mingled with the blocks of schistose Cambrian quartzite. Upon the north side of the Kern Mountains granite is found in contact with the schistose Cambrian quartzite and also with the overlying metamorphic limestones. The central portion of the Kern Mountains is made up of this granite, with the Cambrian rocks on the flanks. A specimen examined microscopically proved to be a biotite-muscovite-granite, approaching alaskite. On the borders of the granitic mass are found siliceous granitic dikes, which cut the Cambrian quartzite-schists. At one locality, which is on the southwest side of Pleasant Valley and near the State line, is found a broad belt of confused alaskite dikes showing a tendency to change into a muscovite-biotite-granite on the one hand and into large quartz veins on the other.

Howell[a] notes that at the head of Deep Creek, only a few miles north of Pleasant Valley, the erosion of the creek has laid bare granite underlying the quartzite and limestone. From here northward to Uiyabi Pass, not far from the northern end of the range, he notes that the base of the range is granite, overlain and flanked on the west by quartzite and limestone.

From these evidences it would seem that the limestones and overlying quartzites which form the base of the stratified series in the Snake Range, and which will be presently shown to be Cambrian, are ordinarily underlain by granite. But in at least one locality similar

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 242.

A. JEFF DAVIS OR WHEELER PEAK, SNAKE RANGE FROM ROBINSON'S RANCH



B. NORTH END OF SCHELL CREEK RANGE FROM ANTELOPE RANCH

Showing also the Tertiary and Pleistocene valleys between the two ranges

granitic rock is locally intrusive into the Cambrian strata, and the same has been suspected in other places. From the fact, however, that the intrusive phenomena are of minor importance, and also from the circumstance that where the Cambrian quartzite is schistose the underlying granite also shows signs of movement, the writer inclines to the belief that the granite as a whole is really Archean and is the basement upon which the Cambrian quartzites were laid down. So thick a series of quartzites (amounting to several thousand feet) naturally suggests a granitic land mass as their source. As regards the occasional intrusive phenomena, it is possible that these represent occasional outbursts of molten rock which found its way from the lower and more heated regions up through the crust of hard Archean granite and into the overlying Cambrian, being intrusive into the Upper Archean as well as into the quartzites, although belonging practically to the same body as the basement granite. The writer would suggest that this explanation may possibly apply to Big Cottonwood Canyon, in the Wasatch, near Salt Lake City, where the granite was originally believed to be Archean, but where later observers have noted intrusive phenomena.[a]

SEDIMENTARY ROCKS.

CAMBRIAN.

In the southern part of the range, at Wheeler Peak, there are heavy quartzites dipping in all directions, forming a gentle quaquaversal. Howell[b] notes the same quartzites for some distance south of the peak, overlain by heavy bluish-gray limestones. He estimates the limestones as 4,000 to 5,000 feet thick, and the underlying quartzite at not less than 1,000 feet.

North of Wheeler Peak, at the mining camp at Osceola, the writer observed these quartzites, and found on the mountain just south of the camp about 500 feet of pure white quartzite underlain by about 2,000 feet of massive gray quartzite, with some silvery slate. At Osceola there is an east-west fault which brings together a massive brown craggy-weathering quartzite on the north side and the silvery slate with quartzite bands on the south. Above the quartzite, one mile east of Osceola, there is a high bluff of dark-blue frosty lustered siliceous limestone with indistinct, probably organic, markings, similar to the limestones just west of here, in the Schell Creek Range. About a mile farther east the slight westerly dip of the limestones brings up the same underlying silvery slates as were noted in the neighborhood of Osceola and also in the Schell Creek section at the same horizon. The limestones in the neighborhood of Osceola were estimated at 1,000 feet thick, while the slates, as exposed in the Schell Creek section, were roughly estimated at from 4,000 to 5,000 feet. A short

[a] C. R. Van Hise, Correlation Papers, Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, p. 289.

[b] *U. S. Geog. Surv. W. One Hundredth Mer.*, Vol. III, p. 241.

distance farther east the slates are underlain by 300 feet of brown quartzite like that at Osceola, below which comes 600 feet of gray quartzite.

The following observations have been directly communicated to the writer by Mr. F. B. Weeks, who made an extended trip in the Great Basin region in the summer of 1900:

A few hundred feet below the summit of the ridge south of Osceola fossils were found in the limestone and have been determined by Mr. Walcott as Lower Cambrian.

About 8 miles northeast of Osceola the center of the range is occupied by hard and massive drab and blue limestones, in which fossils collected at two localities have been determined by Mr. Walcott to be Middle Cambrian forms. These Cambrian limestones are succeeded by Ordovician limestones.

We have, then, in the neighborhood of Osceola a section of sedimentary rocks resting upon the basal granite and consisting of at least 2,500 feet of quartzites, succeeded by a thickness of silvery, somewhat micaceous slates of uncertain but probably considerable thickness, and these by at least a thousand feet of metamorphic limestones. The section is identical with that just west of here, in the Schell Creek Range.

About 20 to 25 miles south of Wheeler Peak Cambrian limestones, overlain by Ordovician limestones, were also observed by Mr. Weeks.

All along the eastern side of the Snake Range, north of Wheeler Peak, is found the same section, although the overlying silvery slates often become more quartzitic and pass into quartzite-schists. Just north of the east-west gap crossing the range north of Wheeler Peak a series of 2,500 to 3,000 feet of craggy-weathering brown or black considerably altered limestones, reticulated by many veins and highly jointed, was gone through. In this limestone no fossils were seen, but above it is found limestone with Coal Measures fossils. The lower limestone is believed to be in part Cambrian, for below it was found a belt of about 200 feet of black shale, in which a number of fossils were collected, which were determined by Mr. C. D. Walcott to be Cambrian. Below this shale comes a peculiar 50-foot bed of white marble, banded with gray, and beneath this upward of 1,500 feet of highly schistose quartzite, producing the effect of a silvery slate.

From here north to the transverse gap which cuts across the range south of the so-called Kern Mountains, one finds almost continuously the same quartzite-schists at the bottom of the section, sometimes nearly approaching the condition of a mica-schist. Above this come heavy bedded limestones, which weather brown, and which carry indistinct and indeterminable fossil remains. Midway between the northern end of the main portion of the Snake Range, south of the Kern Mountains, and the Kern Mountains themselves, the same metamorphic limestone was found in a butte.

From observations all along this face of the range the thickness of the metamorphic limestone was estimated at about 5,000 feet. A spec-

imen of the limestone examined appeared to contain indistinct traces of organic forms, but was thoroughly recrystallized.

At the southeastern end of the Kern Mountains the same highly altered limestone was found. Farther northwest, toward the heart of the mountains, this is underlain by highly altered quartzite-schists with an intercalated band of marble similar to the section described farther south. The schist is cut by numerous dikes of siliceous granitic rock, as above described. Thin sections of the schist examined proved that it was originally quartzite, but the more metamorphosed specimens showed the development of biotite and muscovite along sliding planes, producing a muscovite-biotite-quartzite-schist.

In the mountains on the north side of Pleasant Valley Mr. Howell[a] has noted that the range is composed of quartzite overlying granite and itself overlain by limestone. He also notes that there is frequently a little shale between the limestone and the quartzite. At Uiyabi Pass he estimated the limestone at from 3,000 to 5,000 feet. He found there only from 200 to 400 feet of quartzite between the granite and the limestone.

Along the north side of Pleasant Valley, at the base of the Deep Creek Mountains, the writer noted the continuation of the altered limestones that overlie the quartzites and shales of the Kern Mountains. This limestone was traced northwestward to the gap though which the road runs northward to Deep Creek. Immediately west of here it is replaced by less altered limestone carrying Coal Measures fossils.

We have, therefore, extending nearly the whole length of the Snake Range, for 100 miles at least, a heavy quartzite resting upon a basement of granite and overlain by slates, which in turn are overlain by massive metamorphic limestones. The thickness of the quartzite in the neighborhood of Osceola was estimated at not less than 2,500 feet, while Mr. Howell found only 200 or 400 feet at the northern end of the Deep Creek Range. The thickness of the overlying shales or slates seems to be likewise small at the northern end of the range, while in the neighborhood of Osceola it is considerable, and was roughly estimated by the writer, partly by comparison with the adjacent Schell Creek Range section, to be 4,000 to 5,000 feet. The thickness of the massive limestones above was estimated by Mr. Howell at Wheeler Peak at from 4,000 to 5,000 feet; by the writer, at a point some distance farther north, at about 5,000 feet; and by Mr. Howell at Uiyabi Pass at from 3,000 to 5,000 feet. But at the latter locality Howell found Carboniferous fossils, so that at least the upper part of the limestone here can not be included with the Cambrian.

The whole section corresponds in its chief features to the Cambrian section of the Schell Creek Range, the Highland Range, and the section at Eureka, and the Cambrian fossils found in the shale horizon above

[a] U. S. Geol. Surv. W. One Hundredth Mer., Vol. III, p. 242.

mentioned confirms the correlation. We have therefore a roughl estimated thickness of at least 12,500 feet of Cambrian in this range

SILURIAN.

On the road which runs east from Osceola there was observed hard white quartzite about 400 feet thick, which was recognized i the field as similar in every respect to the Silurian Eureka quartzit of the Eureka section.

Northeast of this locality, about 4 miles north of Robinson ranch (Pl. IV, *A*), a compact conglomerate, which will presently b described as probably Mesozoic or Tertiary, contains large quant ties of similar white quartzite, together with limestone fragment From some of the limestone fragments the following Ordovicia (Lower Silurian) fossils were obtained and identified by Prof. E. C Ulrich:

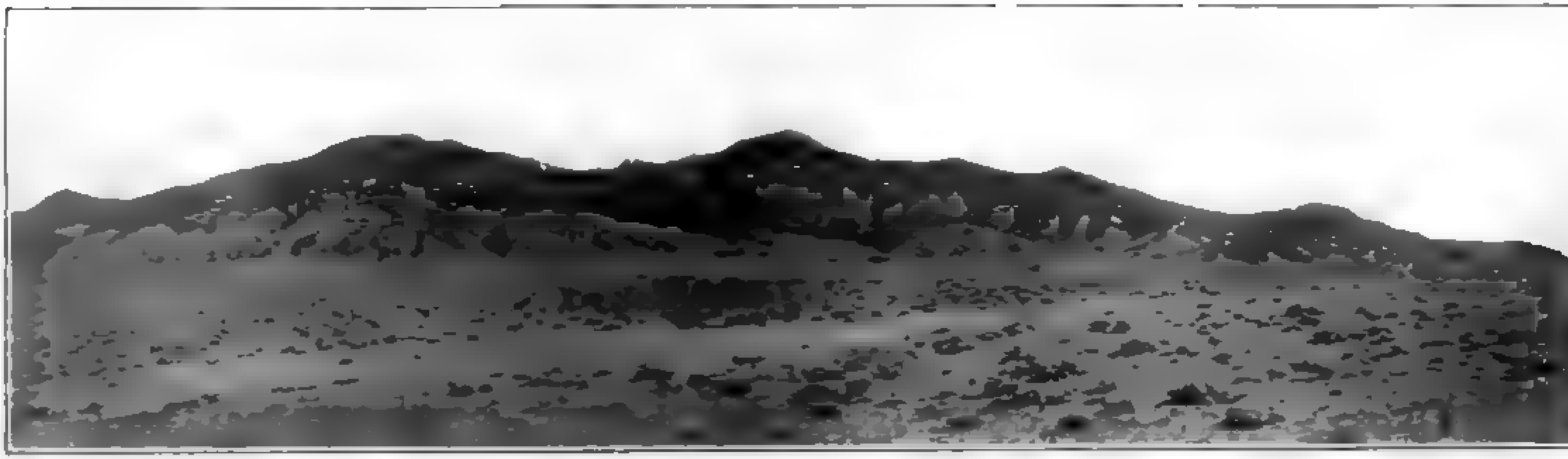
Leperditia fabulites Conrad, variety.
Isochilina, sp. undet.
Lophospira, sp. cf. L. bicincta Hall.
Fragments of an Orthis near Tricenaria.

These conglomerates pass laterally into limestones and whit quartzites, whence they are derived. The *Leperditia* above mer tioned is found in the Pogonip terrane at Eureka, so that the lim stone here is very likely of the same horizon. This also strengther the previous tentative assignment of the quartzite to the Silurian.

Eight miles northeast of Osceola, in the center of the range, M F. B. Weeks[a] observed, overlying Cambrian limestones, a differe series of purple, drab, and white limestones, in which the followin Ordovician fossils were found (determined by Professor Ulrich):

Fragments of crinoid columns.
Orthis (cf. lonensis and holstoni).
Dalmanella (cf. testudinaria).
Dalmanella (cf. emacerata).
Dalmanella (cf. perveta and pogonipensis).
Brachiopod of undetermined relations.
Maclurea.
Eccyliopterus (near owenanus (H. & W.) Ulr.).
Helicotoma sp. undet.
Lophospira?
Cyrtoceras ? (very small).
Related to Serpulites dissolutus Billings.
Asaphus—fragments. (1)
Asaphus. (2)
Asaphus sp. undet. (3)
Asaphus (cf. curiosus). (4)
Bathyurus sp. undet.
Cyphaspis ? sp. undet.
Two undet. trilobites.
Illænus (cf. americanus Billings).
Amphion (near salteri Billings).
Amphion nevadensis Walcott.

[a] Personal communication to the writer.



A. SNAKE MOUNTAINS NORTH OF ROBINSON'S RANCH.

Mr. Weeks states that about 20 to 25 miles south of Wheeler Peak, in the bold escarpment 1,500 to 2,000 feet in height which faces Spring Valley, the Ordovician limestones abut against the Cambrian with a very high angle of dip. In this series the following fossils, determined by Professor Ulrich, have been collected:

First lot.

Orthis (near tricenaria).
Orthis (? type of plicatella).
Orthis (cf. bellarugosa).
Orthis n. sp. (near O. holstoni Safford).
Dalmanella (type of testudinaria).
Dalmanella (type of perveta).
Dalmanella.
Hormotoma (near gracilis).
Leperditia bivia White.
Leperditella sp.
Leperditella ? sp.
Schmidtella n. sp. (near crassimarginata).
Bathyurus (? Dikellocephalus). Occurs elsewhere.
Bathyurus.
Amphion.
Asaphus.
Asaphus.
Asaphus ? curiosus (Billings) Walcott.

Second lot.

Fragments of large cystidean or Carabocrinus.
Orthis tricenaria-costalis.
Orthis pogonipensis ?
Orthis n. sp. (near O. holstoni Safford).
Eccyliopterus—fragment.
Endoceras of new type.
Leperditia bivia White.
Leperditia n. sp. (near bivia and fabulites).
Leperditia n. sp. (semipunctate).
Schmidtella n. sp.
Illænus sp. (? Thaleops).
Amphion nevadensis Walcott.
Bathyurus ? n. sp. (Occurs at many localities.)

These fossils are types that were found by Mr. Walcott in the Lower Pogonip (Ordovician) at Eureka, and it is not probable that an erosion interval of much importance occurs at this horizon.

The Carboniferous strata lie unconformably upon the Ordovician in nearly horizontal position, and form the remaining portion of the Snake Range. Between the Ordovician and the Carboniferous there is a great interval of nondeposition, since the Eureka quartzite, the Lone Mountain limestone of the Silurian, and the whole of the Devonian as exposed at Eureka, are wanting in this section.

CARBONIFEROUS.

Mr. F. B. Weeks[a] reports that near the southern end of the Snake Range the Lower Silurian (Pogonip) rocks are directly overlain by Carboniferous limestones. There is here a gap in the Paleozoic section. The upper formations of the Silurian as exposed at Eureka (the Eureka quartzite and the Lone Mountain limestone) are wanting, as well as the whole Devonian section (8,000 feet thick at Eureka). In a low pass near the southern end of the Snake Range Carboniferous fossils were found, which were determined by Dr. Girty as containing species of *Zaphrentis*, *Syringopora*, and *Reticularia*.

In the section across the range eastward from Osceola, and just north of Wheeler Peak, the Cambrian rocks are succeeded to the east by a conglomerate made up chiefly of the peculiar metamorphic Cambrian limestones, and also containing pebbles of the quartzite and calcite veins which these limestones hold. Between this locality and the next outcrop to the west (which consists of Cambrian quartzite and limestones), there is a gap of a few miles, covered by a drift in which no rock outcrops were observed. Succeeding this on the east is dark-gray, somewhat fetid, calcite-veined limestone, which is very fossiliferous. This locality yielded the following Upper Carboniferous fossils, which were determined by Dr. George H. Girty:

Fistulipora ? sp.
Productus n. sp.
Productus sp.
Marginifera splendens.
Spirifer boonensis.
Ambocœlia planiconvexa.
Seminula subtilita.

This is lithologically the same rock as the Upper Carboniferous on the west side of the Schell Creek Range, where it also abuts against the Cambrian.

This fossiliferous bed is succeeded farther east by similar limestones and by beds of ferriferous quartzite. After about three-quarters of a mile there comes in about 400 feet of hard white quartzite, which is supposed to be Silurian.[b] The dip of this flattens so that it forms the outcrops and the tops of the hills for a half mile east. Then comes in, farther east, conglomerate made up of limestone fragments in a reddish, finely triturated matrix. The fragments yielded the following Upper Carboniferous fossils, which were identified by Dr. George H. Girty:

Productus prattenianus.
Productus portlockianus?
Marginifera splendens.
Spirifer cameratus.
Seminula mira?

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[a] Personal communication to the writer.
[b] See p. 30.

Proceeding northward from this point along the eastern face of the mountains, there was found, about 4 miles north of Robinson's ranch, a compact red conglomerate, made up mostly of white quartzite and crystalline limestone full of calcite veins. The limestone fragments yielded the following Ordovician (Lower Silurian) fossils, which were identified by Dr. George H. Girty: Fragments of *Orthis* sp. and *Leperditia bivia*.

From another fragment the following Upper Carboniferous fossils were obtained: *Rhombopora?* sp. and lamellibranch fragments.

The angular shape of these fragments proves a shore formation. Two hundred yards north the conglomerate passes laterally and rapidly into the solid rocks from which it is derived—black, dark-blue, and gray limestones, thoroughly seamed and crushed, and white quartzite, having nearly the same attitude as the conglomerates. The solid limestone carries fossils like those in the conglomerate. Following the section northward, one passes through 2,500 or 3,000 feet of limestone to a belt of black shale in which Cambrian fossils were found, as determined by Mr. C. D. Walcott.

From here northward as far as Pleasant Valley no Carboniferous fossils were found. On the north side of Pleasant Valley the metamorphic limestones, which have been referred to the Cambrian, are succeeded to the west, near the gap where the road to Deep Creek runs, by comparatively unaltered although calcite-veined limestones, which carry the following Upper Carboniferous fossils, as determined by Dr. George H. Girty:

Romingeria? sp.
Fenestella sp.
Productus prattenianus.
Seminula mira?
Pugnax rockymontanus.
Dielasma? sp.
Edmondia? sp.
Pleurotomaria sp.
Bellerophon crassus?

Farther north, at Uiyabi Pass, near the northern end of the range, Mr. Howell found a few fossils, among them *Fusulina cylindrica*, which indicate Carboniferous age. These fossils were found in Carboniferous limestone which lies above the Cambrian quartzite, and probably in the upper part of the limestone, the lower part being presumably Cambrian.[a] This limestone, according to Mr. Howell,[b] is about 4,000 or 5,000 feet thick.

MESOZOIC OR TERTIARY.

As described above, there was found on the road leading east from Osceola a folded conglomerate made up of coarse limestone frag-

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[a] See p. 29. [b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 242.

ments carrying Upper Carboniferous fossils and evidently derived from immediately adjacent Upper Carboniferous strata. This conglomerate may be part of a series which was examined for 4 miles farther east, and seems to consist mostly of gray sandstones. The sandstones are tilted toward the west, sometimes at angles of 45°, but in one place seem unconformable with a knob of underlying limestone. In the mountains a few miles north of Robinson's ranch, as before noted, there was found a compact red shore conglomerate, composed of limestone fragments carrying Ordovician and Upper Carboniferous fossils. This is 100 feet thick, and below it comes 50 feet of consolidated black limestone talus; below the talus is again 500 feet of reddish conglomerate. This series dips 45° to the west, but 200 yards farther north it seems to pass laterally into the solid rocks from which it is derived.

It thus appears that above the Upper Carboniferous limestone, and separated from it by a distinct erosion interval, if not by an unconformity, is a thick series of gray sandstones and limestone conglomerates. We have no means of determining the age of these rocks. In its physical characters the series corresponds roughly to the Triassic described in the Wasatch and eastward by Mr. King.[a] It may also be possibly Eocene.[b]

PLIOCENE.

At the southeastern end of Pleasant Valley is a considerable area of level-topped hills, which rise about 1,500 feet above the valley, and are symmetrically eroded. They are composed of horizontal, slightly consolidated sands, with ledges of conglomerates. At the base of the series the material is coarse and little arranged.

Just north of here, on the west side of Deep Creek Valley, Mr. Emmons[c] has described beds of fine sand and marls, with some gravel conglomerate, and notes that they have a general lithologic resemblance to the Humboldt Pliocene.

The Pleasant Valley strata also correspond in general appearance to the supposedly Pliocene sands and gravels which are found over so large a part of Nevada. They are far above the shore of Lake Bonneville, as indicated by Mr. Gilbert,[d] and therefore appear to belong to a body of water more ancient and probably more extensive than the Pleistocene lake

PLEISTOCENE.

Mr. Emmons[e] noted at the northern end of the Deep Creek (or Ibenpah) Range the terraces of a former lake, of which the highest was

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[a] U. S. Geol. Expl. Fortieth Par., Vol. I, pp. 260, 268, 344.
[b] Ibid., p. 375.
[c] Idem, Vol. II, p. 475.
[d] Mon. U. S. Geol. Survey Vol. I, map.
[e] Op. cit., p. 473

about 800 feet above the desert level. This is perhaps one of the terraces of the Pleistocene Lake Bonneville, afterwards described by Mr. Gilbert.

IGNEOUS ROCKS.

LAVAS.

At the southeastern end of Pleasant Valley occurs a series of small buttes of hornblende-andesite. On the west end of this valley a moderately large area at the base of the mountains is of augite-aleutite.

DIKE ROCKS.

Along the north side of the Kern Mountains, in Pleasant Valley, many acid dike rocks, varying from siliceous alaskite to muscovite-biotite-granite, were found cutting the Cambrian quartzites and limestone. Associated with these dike rocks are abundant quartz veins. It is believed that these dikes have some connection with the probable Archean granite which underlies the quartzites. A specimen of this granite, taken a few miles west of the dikes, proved to be biotite-muscovite-granite.

STRUCTURE.

FOLDS.

The general structure of the Snake Range, between Wheeler Peak and the Kern Mountains, appears to be anticlinal, although the rocks are mostly worn away from the eastern limb. The axis of the fold runs along the east side of the mountains and is marked by a north-south depression, with high hills to the east and the bulk of the range to the west. The general dip on both sides of the axis is perhaps not more than 20°, although it increases locally to 45° and even more.

In the neighborhood of Wheeler Peak, also, the rocks form a gentle anticline. There is also cross folding, with an east-west axis, so that the peak occupies the center of a quaquaversal. A short distance south of the peak the western half of the principal north-south striking anticline is removed, leaving the ridge monoclinal.[a]

At the northern end of the range Mr. Howell[b] noted that the structure of the range is anticlinal at Uiyabi Pass, but from there to Pleasant Valley it is apparently monoclinal, only one limb of the anticline being exposed.

The Kern Mountains, south of Pleasant Valley, appear to consist of an anticlinal fold, with northwest-southeast axis transverse to the general trend of folding

FAULTS.

Mr. Howell[b] noted a cross fault running east and west about 4 or 6 miles north of Wheeler Peak, having a downthrow to the south.

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[a] U. S Geog. Surv. W. One Hundredth Mer., Vol. III, p. 241.

[b] Ibid.

The writer recognized this fault, and 4 or 5 miles north of it a parallel fault, which seems also to have been downthrown to the south.

Mr. Weeks[a] states that about 10 miles northeast of Osceola, in the central part of the range, the Cambrian limestones are broken by numerous faults which strike northwest and southeast. The massive blue limestones which form the upper part of the series are repeated several times by small faults of 200 to 300 feet throw. The general dip of the Cambrian series is to the north-northwest, and the dip of the Ordovician to the east-northeast. There appears to have been an upthrust of the Cambrian which has brought the successive limestone beds of the series in juxtaposition with the Ordovician. The existence of a heavy fault between the Cambrian and Ordovician is clearly seen in the southern portion of the Snake Range.

On the north side of the Kern Mountains a belt of quartz veins and siliceous granitic dike rocks, running northwest along the base of the mountains, appears to be along a fault zone. On the north side is the crystalline nearly black Cambrian limestone, while on the south side come schists which represent the top of the underlying Cambrian quartzite. The vertical separation of the fault is probably at least several hundred feet.

ORES.

At Osceola, just north of Wheeler Peak, the Cambrian quartzites and slates carry gold. Considerable placer and some vein gold has been taken from this district.

On the east side of the range there are small mines and prospects in a number of places. In some localities the coincidence of mineralization with the presence of a spring flowing in a box canyon leads to the hypothesis that it was these same waters which formerly brought about the ore deposition. Along the walls of such canyons, high above the present bed, ancient water channels in the limestone rock show that the spring has existed since near the time when the erosion of the canyon began.

CEDAR RANGE AND CLOVER VALLEY MOUNTAINS.

The Cedar Range consists of broad, irregular, often mesa-like hills, lying south of the Snake Range and northeast of Pioche. Southward from the Cedar Range, and between it and the Mormon Range, there lies to the east of Meadow Valley a wide area of irregular mountains with no definite system of ridges. In these mountains is Clover Valley, whence is taken the name applied here.

The Cedar Range and the Clover Valley Mountains may be considered together for purposes of description. They have been partly mapped by the Wheeler survey,[b] and they have been observed by the writer at several points. So far as known, they consist entirely of lavas.

[a] *Personal communication to the writer.*

[b] *U. S. Geog. Surv. W. One Hundredth Mer.*, atlas, geologic map No. 58.

The geology of these mountains has not been studied in detail, but it is undoubtedly much the same as that described in Meadow Valley Canyon,[a] which is a chasm cut deep into the same volcanic series. By analogy with the rocks in this canyon, we may suppose that the lavas of the mountains under consideration are associated with derived sediments and that these lavas were ejected at different periods. The rock species will probably be found to be varied, ranging, as in Meadow Valley Canyon, from basal rhyolite through andesites, dacites, latites, etc., to the youngest rhyolite and olivine-basalt.

ANTELOPE RANGE.

The Antelope Range is a comparatively insignificant group, about 30 miles long, lying just west of the northernmost portion of the Snake Range (Deep Creek Range).

The central part of the range possesses a topography of considerable relief, with an especially bold face on the east side (Pl. IV, *B*), while on the north and on the south ends the mountains give way to low hills, which finally disappear under the Pleistocene detritus of the valleys.

SEDIMENTARY ROCKS.

On the eastern side of the range, about 3 miles west of Warm Springs, the Eureka quartzite is exposed near the base of the mountains, measuring about 200 feet in thickness. Above this come 700 to 800 feet of dark-blue (probably Lone Mountain) limestone, having the characteristic texture of this formation in the Eureka district. From here to the crest of the range comes limestones (probably Devonian?) consisting of dark-blue and gray alternating bands. From the extreme base of the mountains the following fossils were found: *Leperditia bivia?* White (very poor); *Dalmanella perveta?* They are Ordivician (Lower Silurian) species, as determined by Prof. E. O. Ulrich. These fossils are characteristic of the Pogonip horizon at Eureka.

To the north of this locality, along the eastern face of the mountains, the strata lower gently, so that the probable Lone Mountain and Nevada formations (Upper Silurian and Devonian) extend for several miles. To the south the strata rise and the Eureka quartzite passes half way to the top of the mountains, exposing the underlying Pogonip (Lower Silurian) beds.

This belt of stratified rocks is cut off to the north and to the south by the volcanic rocks which form the greater part of the range.

IGNEOUS ROCKS.

Along the eastern base of the range, at the foot of the mountains composed of Paleozoic strata, there is a belt of foothills about 3 miles

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[a] See p. 139.

wide composed of lava. The same lava evidently underlies the detrital deposits in the whole valley between the Antelope Mountains and the Kern Mountains in the Snake Range, as is evidenced by occasional volcanic buttes which project above the Pleistocene detritus. A few miles south of Warm Springs, near Antelope Spring, the volcanic rock invades the stratified rock in large masses and soon forms the whole of the mountains. From this point along the road which leads from the southern part of the Antelope Mountains to Schellbourne and Cherry Creek there is nothing but the same reddish lava, and, so far as was seen, the lava seemed to extend northward to the end of the range.

Specimens of the lava collected at various points throughout the southern part of the range prove to be in general a pyroxene-aleutite. It is essentially the same rock which stretches across the intervening valley to the foothills at the western base of the Snake Range, north of the Kern Mountains. The same body of lava also fills the whole valley between the Antelope Mountains and the northern part of the Schell Creek Range, and extends to the summit of this range.

The lava constituting the northern part of the range has been described by Mr. Emmons[a] as rhyolite.

STRUCTURE.

Where the Paleozoic rocks are exposed in the Antelope Range the strike is in general north and south and the dip 20° W. On the western borders of the Snake Range, directly east of here, they have a general dip of 15° E. The intervening valley is, therefore, perhaps anticlinal. The structure of the stratified rocks of the Antelope Mountains is obscured by the overlying lavas.

SCHELL CREEK AND HIGHLAND RANGES.

The Schell Creek Range has its northern end at the fortieth parallel (Pl. III, *B*) and extends from here southward about 100 miles to Patterson. Here a slight gap separates it from the Highland Range, which is a direct continuation of it. The Highland Range extends from Patterson southward for about 80 miles, when it runs into the Meadow Valley Range, from which it is separated by no distinct gap. The Meadow Valley Range will be described later.

SEDIMENTARY ROCKS.

CAMBRIAN.

At the northern end of the Schell Creek Range, in the vicinity of Schellbourne, Mr. Emmons[b] noted limestones carrying Cambrian fossils and overlying heavy bodies of Cambrian quartzite. Mr. Gilbert[c]

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[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 485.
[b] *Ibid.*, p. 486.
[c] *U. S. Geog.* Surv. W. One Hundredth Mer., Vol. III, pp. 30, 182.

noted also Cambrian fossils near Schellbourne and also both north and south of it. In Ruby Hill Canyon, about 10 miles south of Schellbourne, quartzites were noted at the eastern base of the range, overlain by several thousand feet of limestones. About 18 or 20 miles south of Ruby Hill and a few miles south of Piermont, at Whites Peak, the quartzites have risen to the crest of the range and together with the associated schists display a thickness of over 11,000 feet. The strata dip 15° or 20° W., and the overlying limestone appears on the west flank of the peak. Southward from Whites Peak the quartzite gradually sinks again, and the crest of the range is made up of the overlying limestones.

The writer crossed the Schell Creek Range at Schellbourne and found the eastern side composed of volcanic rock. A quarter of a mile east of the summit dark-blue massive limestone begins. Underlying this limestone, on the west side of the pass, occurs dark-blue limy shale, containing Cambrian fossils, as determined by Mr. C. D. Walcott.

This shale is several hundred feet thick and contains a bed of fine-grained brown-weathering quartzite 100 feet thick. Similar fossils are found above and below the quartzite. Beneath the shale comes a well-bedded limestone.

In the west-facing scarp of the mountain, directly north of the pass as seen from Schellbourne, the section examined may be seen finely exposed. From stratigraphic evidence the writer would be inclined to correlate the uppermost limestone with the Hamburg formation of Eureka, the shales with the Secret Canyon formation, and the lower limestones with the Prospect Mountain limestone. An estimated section of the mountains here is as follows:

Section near Schellbourne.

	Feet.
Hamburg limestone	600
Secret Canyon shale	600
Prospect Mountain limestone	1,800

Neither the top nor the bottom of the section was observed.

About 30 miles south of Whites Peak and Piermont the writer crossed the Schell Creek Range along the main road between Ely and Osceola. On the east side of the summit (which is not high at this point) limestone carrying abundant Carboniferous fossils appears to abut against massive dark-blue metamorphosed limestone, reticulated with calcite veins, and associated with beds of marble. Immediately below the metamorphic limestone beds is a ferruginous and micaceous slate seam, contorted and containing veins of quartzite and calcite. This limestone and underlying schistose slates constitute the whole eastern part of the range.

No fossils were found at this point, but the beds are probably to be correlated with the Cambrian limestones and underlying shales at

Whites Peak, at Ruby Hill, and Schellbourne. The succession and the general character of the rocks are also similar to those of the Cambrian limestones and shales in the Highland Range in the vicinity of Pioche and in the Snake Range directly east of here, in both of which localities Cambrian fossils have been found.

On the west side of the range, north of the locality just described and directly east of Ely in the Egan Range, the ridge which flanks the main Schell Creek Range on the east has along its crest what appears from a distance to be the white Eureka quartzite of the Silurian, dipping west at a constant angle of about 30°. Between this ridge and the main range there is a parallel depression which runs along the axis of an anticline, for to the east of it the strata have an easterly dip of from 20° to 30°. On the ridge itself there comes in below the Eureka quartzite strata resembling the thick, comparatively soft limestones of the Pogonip formation, and beneath this, in the bottom of the valley, are exposed massive gray limestones, which are perhaps Cambrian. These Cambrian and Silurian rocks do not extend south past the end of the ridge which forms the western high limb of the anticline, but are replaced to the south by the Devonian, the two regions being apparently separated by a heavy east-west fault.

Mr. Howell[a] has described the rocks at the southern end of the Schell Creek Range. He notes that at Patterson a heavy bed of quartzite is exposed, dipping about 45° ESE. A few miles to the north this is covered conformably by bluish-gray limestone. No fossil remains sufficient for determination were found, but the limestone was correlated on lithologic grounds with the supposedly Carboniferous limestones of the Snake Range and the Highland Range. Inasmuch as at least the southern portion of the Highland Range consists of Cambrian limestones, which were classed by Mr. Howell as Carboniferous, but subsequently definitely determined as Cambrian, and since the same Cambrian series occurs in the Snake Range, it seems likely that these rocks may also be Cambrian.[b]

At the north end of the Highland Range, just south of Patterson, Mr. Howell found Carboniferous limestone well characterized by fossils.

At Bristol, on the west side of the range, and about 30 miles south of Patterson, Mr. Howell noted quartzite at the base, while the whole upper portion was highly metamorphic limestone. This section, so far as it goes, accords with the Cambrian section of the southern end of the range, as will be mentioned later.

Mr. Walcott[c] noted on the western side of the range, at the same locality as just mentioned, the occurrence of the Eureka quartzite. It is possible that this is the same quartzite mentioned by Mr. Howell.

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 232.

[b] Subsequent to the writing of this Mr. F. B. Weeks collected Cambrian fossils near Patterson, in these limestones, above the quartzites.

[c] *Bull. U. S. Geol. Survey No. 30*, p. 36.

The writer passed only a few miles from Bristol, proceeding from Coyote Spring over Stampede Gap, and he also mapped the Silurian as extending across the valley to Bristol, and indicated in his notes the probable occurrence of the Eureka quartzite.

At Stampede Gap the range, with the exception of some very low foothills at the western base, which will be referred to later as probably Devonian or Silurian, is composed of about 800 feet of mingled limestone and slate overlain by about 1,400 feet of massive limestone containing siliceous beds. Some of these upper limestones carry indistinct and indeterminable organic remains. A mottled structure, seeming to indicate the former presence of coral remains in the now altered rock, is common, being the same structure as observed in the Cambrian rocks of the Schell Creek Range, described above as occurring about 30 miles south of Piermont. In the limestones at both localities metamorphism has caused the same peculiar pitted appearance which results from the segregation of metamorphic minerals.

In the Highland Range, about 4 miles south of Stampede Gap and about the same distance southwest from Pioche, the entire range appears to be of Cambrian strata, and Mr. Walcott[a] has measured the following section:

Section in Highland Range 4 miles south of Stampede Gap.

	Feet.
1. Quartzite	850
2. Limestone and shales, argillaceous and arenaceous	1,450
3. Massive limestone	3,000
Total	4,800

The fossils which he collected at various points correlated this section with the Cambrian at Eureka, the basal quartzite corresponding to the Prospect Mountain quartzite.

In the Highland Range, south of Bennetts Spring, the writer has noted the probable continuation of the Cambrian section for a distance of 5 or 6 miles at the very least, the section being substantially the same as between Bennetts Spring and Stampede Gap. From the eastern base of the Highland Range abundant quantities of brown quartzite, probably representing the basal Cambrian quartzite of Mr. Walcott's section, come down into the valley drift. This quartzite is probably overlain by the Cambrian limestone, for the strata appear horizontal on the east side of the Highland Range throughout practically its whole length.

At Pioche Mr. Howell[b] noted 400 feet of highly metamorphic blue-gray limestone, and below this about 400 feet of shales, which yielded abundant Cambrian fossils. Below these shales is an unknown thickness of quartzite. He correlated this quartzite with the Cambrian quartzites of the Snake and Wasatch ranges. Mr. Walcott[a] has also

[a] Bull. U. S. Geol. Survey No. 30, p. 34.

[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 243.

studied the Cambrian section at Pioche and finds a thickness of the basal quartzite of 1,200 feet on the west face of the Ely Range, a few miles to the west of the town of Pioche. Mining operations have thrown out large masses of shales carrying Cambrian fossils, which Mr. Walcott[b] has described and correlated with a bed of the Highland Range section. Similar fossils were also collected at the same locality by the writer. This horizon is well up in the shaly limestone which overlies the basal quartzite.

Three or 4 miles southeast of Pioche, along the road to Panaca, what is probably the basal quartzite is slightly exposed, immediately overlain by the shales. From these shales Mr. Walcott collected a number of Cambrian fossils. The writer also collected fossils from this point.

SILURIAN.

In the western face of the Schell Creek Range, just east of Ely in the Egan Range, what is perhaps the Silurian Eureka quartzite appears, forming the crest of a minor ridge, flanking to the west the main Schell Creek Range. The quartzite dips to the west about 30° and is underlain by what appears to be the Pogonip formation. No fossils were collected.

The Silurian rocks above described are probably cut off to the south by an east-west fault, for they are succeeded by Devonian strata.

Mr. F. B. Weeks[c] found, in 1900, that, about 10 miles north of the road leading from Osceola to Ely, the Cambrian beds on the northeast are separated from Ordovician beds on the southwest by a heavy fault. In these Ordovician beds the following fossils, determined by Professor Ulrich, were collected:

Orthis (related to O. bellarugosa).
Dalmanella (near perveta).
Dalmanella (near emacerata).
Modiolodon sp. undet.
Ischyrodonta sp. undet.
Cyrtodonta ? sp. undet.
Maclurea (cf. subannulata Walcott).
Gyronema (near semicarinatum).
Metoptoma sp. undet.
Endoceras (1).
Endoceras (2).
Leperditia (near fabulites).
Leperditella.
Leperditella (with ventral swelling).
Schmidtella n. sp. (near crassimarginata).
Aparchites sp. undet.
Olenus ? sp. undet. (1).
Olenus ? sp. undet. (2).
Asaphus.
Pygidium. sp. undet.

[a] Bull. U. S. Geol. Surv. No. 30, p. 36.
[b] Ibid., pp. 34, 35.
[c] Personal communication to the writer.

Another lot was as follows:

Asaphus (related to Megalaspis belemnurus White).
Two species of trilobites related to Symphysurus goldfussi Walcott.
Leperditella (related to L. inflata).
Undet. ostracod (? related to Octonaria).

Silurian rocks do not appear, so far as yet observed, until the neighborhood of Bristol, where the Eureka quartzite was observed by Mr. Walcott. The writer also has observed probable Silurian rocks, constituting low hills, which connect the Highland Range, in the neighborhood of Bristol, with the irregular ridges lying between the Egan and Pahroc ranges.

Farther south Mr. Walcott[a] has noted the Eureka quartzite on the west side of the Highland Range, in a hill north of the road leading from Bennetts Spring to Hiko. At this point fossils are very abundant.

DEVONIAN.

At the western base of the Highland Range, at Stampede Gap, highly fossiliferous strata were observed, probably separated from the Cambrian strata which form the mass of the range by a heavy north-south fault. No fossils were collected, but from the stratigraphy it seems possible that these are the continuation of rocks in the neighborhood of Coyote Spring, at the northern end of the Pahroc Range, just west from Stampede Gap, which are Devonian.

On the western side of the range, north of the road which crosses it between Ely and Osceola, the writer found dark-blue to gray-blue, often shaly limestone filled with calcite seams. From one horizon in this limestone he collected the following Devonian fossils, which were determined by Dr. George H. Girty: Stromatoporoid coral, *Spirifer utahensis*, and *Ambocœlia umbonata*.

These Devonian strata are apparently separated from Silurian and Cambrian rocks farther north by an east-west fault.

CARBONIFEROUS.

The western half of the Schell Creek Range, where it was crossed on the road between Ely and Osceola, about 20 miles southeast of Ely, is chiefly composed of Carboniferous rocks. They consist mostly of dark-blue, gray-blue, and often shaly limestones, with occasional brown quartzite seams. Some of the beds are semicrystalline. The series throughout is highly fossiliferous.

Just after the road enters the range Upper Carboniferous fossils were collected. They were determined by Dr. George H. Girty, as follows: *Zaphrentis* sp., *Productus* sp., *Spirifer rockymontanus*, *Seminula* sp.

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[a] Bull. U. S. Geol. Survey No. 30, p. 36.

A mile east of the above-mentioned locality the following Upper Carboniferous fossils were collected:

Orbiculoidea missouriensis.
Productus inflatus?
Marginifera muricata.
Cleiothyris orbicularis.
Seminula subtilita.
Rhombopora lepidodendroides.

All these Carboniferous rocks dip to the east 20° or 30°, and apparently abut directly against the Cambrian on the east.

Near the northern end of the Highland Range, 3 or 4 miles south of Patterson, Mr. Howell[a] has noted 2,000 feet of limestone containing well-marked Carboniferous fossils.

IGNEOUS ROCKS.

LAVAS.

In the vicinity of Schellbourne the whole eastern part of the Schell Creek Range is covered by basic lava, and this also overflows to the western part of the range, covering up in patches the stratified Cambrian rocks. This lava is in general a pyroxene-aleutite. According to Mr. Emmons,[b] the extreme northern portion of the range is entirely covered by rhyolite. In the vicinity of Schellbourne the writer found, underlying the basic lava, a few feet of white biotite-rhyolite.

On the western side of the Highland Range, 5 or 6 miles south of its northern end, Mr. Howell[c] has reported lava. Still farther south, at Stampede Gap, the writer observed a small area of rhyolite in the valley at the western base of the mountain.

DIKES.

Mr. Gilbert[d] has noted in Ruby Hill Canyon, a few miles south of Schellbourne, siliceous dikes cutting the Cambrian limestones.

STRUCTURE.

FOLDING.

On the west side of Schell Creek Range, just east of Ely, a conspicuous anticline was observed, trending parallel to the crest of the main range. The axis of this anticline is occupied by a valley, and the western limb is marked by a minor north-south ridge running from about the latitude of Ely northward to the neighborhood of Schellbourne. The rocks exposed in this anticlinal fold are probably Silurian. To the south the fold, and at the same time the ridge in which

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 243.
[b] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 486.
[c] *Op. cit.*, p. 243.
[d] *U. S. Geog.* Survey W. One Hundredth Mer., Vol. III, p. 31.

its western limb is exhibited, are apparently cut off by an east-west fault, while on the north the rocks of the fold pass under the Pleistocene valley detritus. About 10 miles south of the southern end of the minor ridges above mentioned what appears to be the continuation of the same anticlinal fold is exhibited in the foothills on the west side of the range. Still farther south the general strike of the rocks changes from south to southwest, and this anticlinal fold probably passes over into the southern end of the Egan Range, where a series of folds was observed, one of which is perhaps identical with it. Farther south again there is probably another synclinal fold, which also passes over into the Egan Range on account of its southwesterly strike. This is probably followed by an anticlinal fold, such as Howell[a] has described, at the extreme southern end of the range, where the rocks dip east-southeast. Still farther south the several folds which are found in the ridges forming the southern extremity of the Egan Range are probably continuous across the intervening valley to the Highland Range.

The Cambrian rocks, which form the greater part of the eastern portion of the Schell Creek and Highland ranges, are also folded. At Schellbourne the rocks seemed to the writer to dip in general to the east, although the attitude could not be certainly made out. Farther south, at Whites Peak, Mr. Gilbert[b] found the Cambrian rocks dipping to the west at an angle of about 20°. Still farther south, where the writer observed the Cambrian rocks in crossing the range between Ely and Osceola, he found the folding complicated and the faulting considerable.

In the Highland Range the folds in the Cambrian rocks appear to be gentle and of no great extent. Those that were observed were mostly transverse to the range, and in general the disposition of the horizons did not vary greatly from what they would have been had they been horizontal.

FAULTING.

Although no careful examination has been made, the stratigraphy indicates the existence of important faults in the Schell Creek and Highland ranges. These probably belong to two chief systems—one north and south and one east and west. On the road which crosses the Schell Creek Range between Ely in the Egan Range and Osceola in the Snake Range the whole rock series dips to the east. The eastern half of the range is composed of Upper Carboniferous limestones carrying abundant fossils, while the western is composed of metamorphic limestones underlain by schistose mica-slates. The character of these later rocks, together with the succession, enables one to correlate them with the Cambrian rocks found in the same range just north of

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 242.
[b] Ibid., p. 31.

here and also in the Highland and Snake ranges. This implies either an enormous fault or a great erosion gap.

Opposite Stampede Gap the writer crossed the valley which lies on the west of the range from a district where there are abundant exposures of fossiliferous Devonian and Silurian rocks. At the western base of the range he noted in the foothills fossiliferous strata, apparently belonging to the same series, from which, however, he collected no fossil remains. Proceeding farther west he found the whole mountain made up of altered massive limestones, with intercalated shales and schistose slates, which belong to the Cambrian. A few miles north of Stampede Gap, at Bristol, Mr. Walcott found the Eureka quartzite of the Silurian at the western base of the mountains, and the same formation about 15 miles south of Stampede Gap on the road from Bennetts Spring to Hiko. Both these places occupy the same relative position at the western base of the range. Between these Silurian foothills and the Cambrian rocks of the main range there appears to be a great break, bringing about juxtaposition of strata which in their normal stratigraphic succession are separated by nearly 2 miles of intervening sediments. This is believed to be the same break as that previously noted farther north, and it may be either a fault or an erosion gap.

An east-west fault appears to cut the range transversely at a point about 10 miles southeast of Ely in the Egan Range. To the north of this line is an anticlinal fold which exposes probable Silurian or Cambrian rocks. To the south only the eastern limb of the fold is found, the ridge which represents the western limb being cut off. On the south side the rocks carry Devonian fossils.

About 10 miles north of the road which crosses the range between Osceola and Ely Mr. F. B. Weeks[a] observed, in 1900, a strong northwest fault marked by a profound interior valley. Cambrian rocks on the northeast side of the fault are brought against Ordovician strata on the north. The fault cuts across the entire range.

Mr. Howell[b] noted a probable cross fault near the north end of the Highland Range. The line of this fault is continuous with a probable fault line sketched by the writer on the Egan Range, just to the west. The writer also saw, a few miles north of this, what is perhaps a parallel east-west fault, marked by a deep transverse valley in the Egan Range and extending across to the gap which separates the Schell Creek Range from the Highland Range. The displacement of these faults was not measured, but is probably very considerable.

At Pioche there are a number of intersecting faults, some belonging to a northwest-southeast system and some to a northeast-southwest system. The main fault observed by the writer runs through the south end of the town, in a northwest direction. It is marked by a

[a] Personal communication to the writer.

[b] U. S. Geog. Surv. W. One Hundredth Meridian, Vol. III, p. 243.

deep gulch, and has the Cambrian quartzite on the northeast side and the Cambrian shale and limestone on the south. This fault has at least 1,000 feet of vertical separation and may have much more. Other faults are parallel to this, and there are a number of northeast-southwest cross faults with considerable displacement. The effect of these is to cause a certain degree of checkering of quartzite and limestone. The northeast gulch in which Pioche lies seems to mark one of these faults.[a]

EGAN RANGE.

The Egan Range is the next important range west of the Schell Creek and Highland ranges. Its north end lies just north of the fortieth parallel and is included in the maps of the Fortieth Parallel Survey. It extends due southward nearly 150 miles.

TOPOGRAPHY.

Throughout nearly its whole course the Egan Range consists of a single well-defined central ridge, from which the slopes to the valley on both sides are comparatively steep. In the neighborhood of Ely the ridges are slightly broken up, but this is apparently due largely to the presence of igneous rocks. At the extreme south end, also, the main range splits up into several low ridges.

The range is cut through at intervals by transverse valleys connecting the valleys on either side of the range and very little higher than they. Such valleys are found at Egan Canyon and at Ely. Near the southern end of the range there are other deep transverse gaps, which, however, do not cut clear down to the level of the valleys.

ARCHEAN ROCKS.

Mr. S. F. Emmons[b] has described the rocks in an outlying ridge on the east side of the range, just south of the eastern end of Egan Canyon. Here the lowest formation exposed is a mica-granite, which is overlain by quartzites and quartzitic schists referred to the Cambrian. The granite is referred to the Archean.

SEDIMENTARY ROCKS.

CAMBRIAN.

As above noted, Mr. Emmons found overlying the granite at the eastern end of Egan Canyon several thousand feet of quartzites and quartzitic schists, together with a 50-foot bed of argillite. These quartzites are overlain by limestones.

The same locality was observed by the writer from a distance, and on account of the stratigraphy was referred with little hesitation to

[a] These observations are in accordance with those previously made by Mr. Howell (U. S. Geog. Surv. W. One Hundreth Mer., Vol. III, pp. 257-261), as the writer discovered since writing the above.

[b] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 488.

the Cambrian. The rocks were not visited, but at the base are heavy beds dipping to the west at an angle of about 30° and striking north and south. These massive beds resemble the Cambrian quartzite and limestone, while above them come more easily eroded limestones, which correspond in thickness and position to the Silurian Pogonip formation. Above the Pogonip on the east face of the main ridge (which is separated from the spur above mentioned by a trough of erosion) is exposed the Eureka quartzite, which is traceable along the range for several miles northward. The identification of this Silurian makes the reference of the easterly rocks of the outlying spur to the Cambrian safe.

Mr. F. B. Weeks[a] reports that in the summit of the range, about 10 to 12 miles south of Egan Canyon, the following Upper Cambrian fossils, determined by Mr. Walcott, were collected:

Obolus (Lingulella) discoidensis H. & W.
Obolus (Lingulella) manticulus White.
Obolus (Lingulella) punctatus Walcott.
Ophileta?
Agnostus, 2 sp.
Ptychoparia, 2 sp.

Along the southern part of the Egan Range the west face, which confronts the southern part of Sierra Valley, exposes some magnificent sections of strata. These also were not visited any farther north than the vicinity of Adams's ranch on White River, near which point they were found to be Devonian. Farther north, however, a thick section of rocks, striking northeast and dipping southeast at an average angle of 30°, was exposed, and the circumstance that the strike is diagonal to the north-south face of the range brings it about that progressively lower beds are exposed going north. About 2 miles north of the vicinity of Butterfield Spring what was taken to be Eureka quartzite was seen at a distance; below this occurs a great thickness of more easily eroded limestones, which were referred to the Pogonip formation; and beneath these again massive limestones, which perhaps represent the Upper Cambrian. Only a comparatively slight thickness of the latter limestones is exposed, when the dip of the section is reversed and becomes northwest, so that the section begins to ascend toward the north.

SILURIAN.

Mr. Emmons[b] noted the finding of Silurian fossils in the limestone in the neighborhood of Egan Canyon. The writer, who crossed the range at this point from Cherry Creek westerly, did not succeed in finding any good fossils, but identified the formations on lithologic and stratigraphic grounds as notably belonging to the Pogonip, the

[a] Personal communication to the writer.
[b] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 488.

Eureka, and the Lone Mountain formations of the Silurian as exhibited in the Eureka section. In the easterly spur of the mountains just south of Egan Canyon, as above noted, the whole thickness of the Pogonip strata is exposed, occupying a valley of erosion between this spur and the main ridge. On the easterly face of the main ridge the Eureka quartzite is exposed, and may be traced across Cherry Creek and still farther north. Above the quartzite, in ascending from Cherry Creek westerly, dark-blue crystalline limestones, similar lithologically to the Lone Mountain limestones of Eureka, and carrying indistinct fossils, were observed.

The probable exposure of the Eureka quartzite on the western face of the range, near its southern end, has already been noted in connection with the probable Cambrian exposures. It is probable that along here not only the Eureka quartzite, but the whole Silurian section, is exposed.

Crossing the separate low ridges which constitute the connection between the southern end of the Egan Range and the Pahroc Range, what is almost certainly the Eureka quartzite was found about 25 miles northwest of Pioche. Here was found a white vitreous quartzite, rather coarse grained and upward of 100 feet thick, above which lie dark-gray, comparatively thin fetid crystalline limestones, with the fossils too much altered to be recognizable. This is perhaps the Lone Mountain limestone. These Silurian rocks are exposed only along the eroded axis of an east-west anticline, and to the north and south are overlying rocks from which Devonian fossils were collected. The general structure of the beds at this point makes it probable that a little farther northeast a greater thickness of Silurian rocks is exposed, in the valley midway between this point and the Highland Range.

DEVONIAN.

The western face of the Egan Range about 8 or 10 miles north of Cherry Creek is composed of stratified rocks dipping very gently northwest. These stratified rocks are limestones whose appearance suggests the Nevada formation of the Devonian. A short distance north of these, also on the west face of the range, black, shaly, fetid limestones carrying Upper Carboniferous fossils were obtained, while south of the supposed Devonian rocks, in the neighborhood of Cherry Creek, there are exposed Silurian formations, as already mentioned. It is more than probable, therefore, that the intervening rocks are really Devonian. Mr. Emmons has made the same suggestion.[a]

In the canyon which cuts through the range at Ely limestones carrying Lower Carboniferous fossils were found. In these limestones are siliceous beds which may perhaps represent the Diamond Peak quartzite of the Eureka section, beneath which there is a slight

[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 488.

exposure of shaly limestone which may represent the White Pine formation. No fossils, however, were procured from these beds, and their identification as Devonian is only provisional.

At the northern end of the curving spur which joins the main range near this point (Pl. V, *A*), where it passes under andesitic flows just south of Summit stage station *Cyathophyllum* sp. was found, and was referred to the Devonian by Dr. George H. Girty.

This Devonian area, however, is small, since at a distance of 2 miles farther south similar limestones carrying Carboniferous fossils were found.

Devonian rocks make up nearly the whole of the series of low ridges which constitute the extreme southern end of the Egan Range, so far as these rocks were examined by the writer in crossing diagonally from northwest to southeast. In crossing the pass which cuts through the western and main ridge of these mountains, about 10 miles due southeast from Adams's ranch, comparatively thin-bedded fetid limestones were found folded into a syncline striking diagonally to the trend of the pass, and carrying the following Devonian fossils, as determined by Dr. George H. Girty:

Amphipora? sp.
Cladopora? sp.
Stromatoporoid coral.
Chonetes macrostriatus.
Spirifer utahensis.

The corals obtained here make up the greater bulk of the rock, which appears, therefore, to have been a Paleozoic coral reef. Both the fossils and the nature of the inclosing rocks are identical with the fossils and rocks found in the Golden Gate Range, directly west of here and about 15 miles distant.

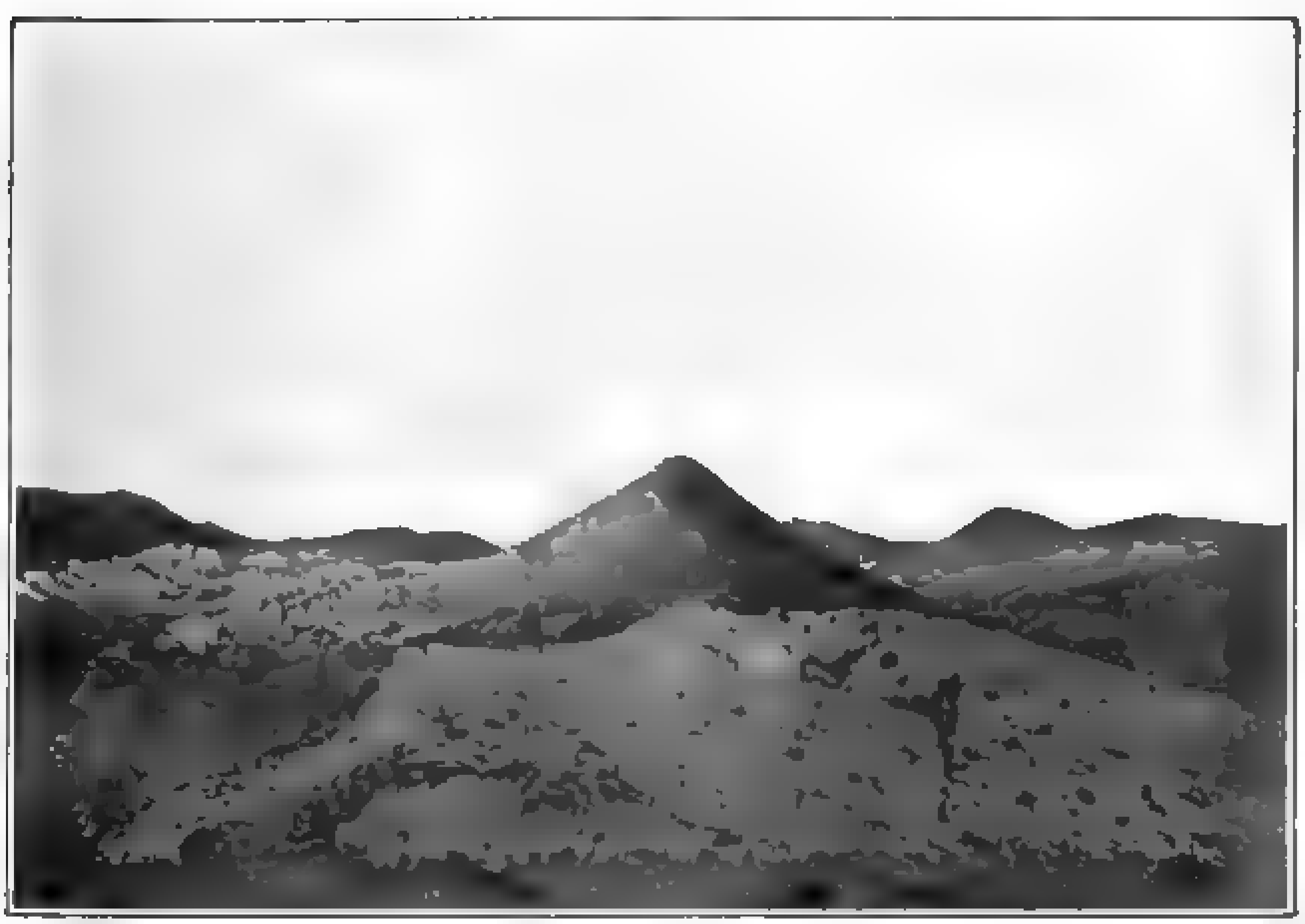
Following the road from here southeastward to Pioche, Devonian fossils were again obtained about 12 miles south of the first locality, as follows:

Amphipora? sp.
Stromatoporoid corals.
Spirifer maia (small variety).

Again about 6 miles farther southeast the following Devonian fossils were collected:

Fucoid.
Productella subaculeata.
Rhipidomella sp.
Spirifer disjunctus.
Spirifer utahensis.
Spirifer strigosus?
Ambocœlia umbonata.
Camarotœchia sappho.
Modiomorpha obtusa?
Grammysia minor?
Loxonema? sp.

A. EAST FACE OF LOW MOUNTAIN RANGE WEST OF EGAN RANGE AT ELY



B. TERTIARY VOLCANIC CONE, PANCAKE RANGE, EAST SIDE OF HOT CREEK

Exposed by denudation of overlying lavas and tuffs

The structure of the surrounding ridges makes it probable that most of them are Devonian.

CARBONIFEROUS.

In the extreme northern end of the Egan Range Mr. Emmons[a] collected probable Carboniferous fossils. On the western front, about 12 miles north of Cherry Creek, the following fossils were collected by the writer and identified by Dr. Girty:

Orbiculoidea missouriensis?
Marginifera splendens?
Productus n. sp.
Spirorbis sp.
Euomphalus catilloides.

Between Egan Canyon and Ely it is probable that the Carboniferous rocks cover a considerable area. Near Ely, Carboniferous limestones are abundantly exposed. About 2 miles south of Summit Springs, on the road between Ely and Hamilton, massive semicrystalline limestones are found which carry a probably Upper Carboniferous fossil that was determined by Dr. Girty as *Zaphrentis* sp.

About 6 miles east of here, on the east side of the narrow valley separating the minor ridge, in which the above fossil was obtained, from the main range, were collected the following Upper Carboniferous fossils:

Seminula subtilita?
Lithostrotion? sp.
Fusulina cylindrica.

Two miles southeast of the last-named locality, near the western entrance of the canyon which cuts through the range at Ely, dark-gray carbonaceous fetid limestones were found which carry the following Lower Carboniferous fossils:

Zaphrentis sp.
Orthothetes inæqualis.
Rhipidomella michelini.
Productus semireticulatus var.
Productus n. sp.
Spirifer centronatus.
Straparollus luxus.
Prœtus peroccidens.

The black shaly limestone which carries the Lower Carboniferous fauna at the last-named locality passes into a belt of red, yellow, and orange weathering shales, with occasional beds of gray, shaly limestone. The thickness of these shales is estimated at from 800 to 1,000 feet. Farther east in the canyon beds of cherty and siliceous limestones also occur in this same series. It is probable that the lowest of these shaly beds are Devonian, but to the south of Ely, above

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[a] U. S. Geol. Expl. Fortieth Par., Vol. II., p. 487

the shales, the more massive limestone comes in above again and extends for 5 or 6 miles at least, striking east and west and dipping gently south.

On the southeastern slope of Hamels Peak, some miles south of Ely, the fossils named below were collected by Mr. F. B. Weeks,[a] and were determined by Dr. Girty. Regarding this collection, Mr. Girty states "The fauna has a similar facies to that of the Marion formation of the Kansas section, which Prosser regards as a true Permian fauna, and it probably can be safely correlated with the Marion."

Productus sp.
Nuculana cf. obesa.
Pleurophorus ? sp.
Schizodus ? sp.
Straparollus catilloides.
Pleurotomaria humerosa ?
Bulimorpha peracuta.
Murchisonia, near marcouiana.
Naticopsis ventricosa ?
Bellerophon sp.
Domatoceras ? sp.
Ostracoda.
Bakewellia parva.

IGNEOUS ROCKS.

LAVAS.

On the west side of the Egan Range, just north of Egan Canyon, a series of low hills are composed of basalt. One of these hills has a conical shape practically unmodified, and, from the circumstance of this slight erosion, the age of the lava must be very recent.

Farther south, also on the west side of the range, is a considerable mass of volcanic rock which has filled up the valley between the southern end of the Long Valley Range and the Egan Range north of Ely. This is, in general, a dacite-andesite and has been deeply eroded, indicating greater age for it than for the basalt.

At the southern end of the range, in the separate low ridges which form the connection of this range with the Pahroc Range, there are large areas of quartz-latite which seem to be continuous with similar lavas occurring in the northern end of the Golden Gate Range and on the easterly side of the Grant Range in the same latitude. As in the other cases described, it is plain that these outflows occurred subsequent to the formation of the deep valleys between the limestone ridges, for the volcanic rock either fills up such valleys or has been poured into them without quite filling them up and now forms their floor. Nevertheless, this volcanic rock is also deeply eroded, and therefore its age is not recent. It may be considered as very late Tertiary or early Pleistocene.

[a] Personal communication to the writer.

DIKES.

At the western entrance of the canyon which cuts through the range at Ely a dike of hornblende-tonalite-porphyry was noted. Farther east in the canyon occur a number of other siliceous dikes. These dikes probably connect with a larger body farther south, which seems to form the crest of the range in the vicinity of Howells Peak.

Just west of the town of Cherry Creek occur a number of dikes which are apparently connected with a larger igneous body a little farther north. Specimens of these dikes show them to be chiefly quartz-monzonites.

STRUCTURE.

FOLDING.

The extreme northern end of the range is said by Mr. Emmons[a] to present an anticlinal fold striking northeasterly, and so diverging from the general trend of the mountains. Farther south, but still north of Egan Canyon, the general structure is plainly synclinal, and has the same northeasterly trend. This syncline must succeed the anticline to the southeast. In the vicinity of Egan Canyon, on the eastern side of the range, the strata on the eastern limb of this syncline dip to the west at angles of from 30° to 45°, which gradually grow less to the west until, at a point about 8 or 10 miles north of Cherry Creek, and on the west side of the range, easterly dipping strata constituting the other side of the syncline are found.

Between the Cambrian rocks on the eastern side of Egan Canyon and the same formations on the west face of the Schell Creek Range, only a few miles to the east, there is probably an anticlinal fold occupying Steptoe Valley.

From Egan Canyon south the Egan Range may be seen to consist of stratified rocks as far as Ely, but the general northeasterly trend of the beds at Egan Canyon changes to a northwesterly one in the mountains north of Hercules Gate, about 10 miles north of Ely. The general structure of the mountains at this point seems to be synclinal, the western limb of the fold being exposed in the Devonian limestone lying just south of Summit stage station on the road between Ely and Hamilton. These limestones dip to the east at an angle of 20°.

From Ely south for a number of miles the strata are not conspicuously folded, but dip gently in various directions, chiefly to the south. The whole southern end of the range, however, from a point about 10 or 15 miles south of Ely as far as the point where the main range begins to split up into several, shows beds which strike uniformly northeast, at an angle with the general north-south trend of the mountains. The farther south one goes the more easterly becomes the strike of the strata, until, in the series of low ridges at the south-

[a] U.S. Geol. Expl. Fortieth Par., Vol. II, p. 486.

ern end of the range, it swings around to east-west and then to southeast, and so runs into the Pahroc Range, where it becomes due north and south.

In this southern part of the range many parallel open folds are exposed. On the west face, about 30 miles north of Adams's ranch, in Sierra Valley, the axis of a broad syncline may be traced, with the rocks on both sides dipping from 10° to 30°. This is followed to the south by a slight anticline and this by a broad syncline, whose axis cuts the mountains about 10 miles southeast of Adams's ranch, at the pass through which runs the road to Pioche. South of here the succeeding anticlines and synclines are frequent and regular. Since their strike is transverse in general to the trend of the ridges and since different ridges are composed of the same rocks, the folds may be traced from one to the other for long distances. Thus, south of the synclinal fold above described a broad anticline was observed, which comprises the rocks for a distance of about 10 miles to the south and which has in general an east-west trend. South of this a comparatively narrow syncline exists, and south of this again an anticlinal fold, which after swinging from an east-west to a southeasterly direction, appears to change still more, till it enters the Pahroc Range with a north-south trend and constitutes the chief fold of these mountains.

In general, therefore, the Egan Range consists of open and symmetrical anticlines and synclines, with the rocks rarely dipping more than 30°. In general these folds trend more easterly than the general trend of the mountains, and thus a number of succeeding folds are exposed.

FAULTING.

In the southern part of the range several deep transverse valleys suggest fault lines, but the examination was too hasty to be sure of their existence.

ORES.

At Mineral City, just west of Ely, lead, silver, and gold, with some copper, are obtained. At this locality a number of siliceous dikes cut up through the limestone, and seem to be connected with the mineralization. In the neighborhood of Ely there are considerable ore deposits. At Cherry Creek also the dikes have perhaps brought about the deposition of the minerals. Some of the ore deposits here run comparatively high in gold and silver.

LONG VALLEY RANGE.

Long Valley Range consists of low limestone mountains. Its southern end, just east of Hamilton, is united with the White Pine Range by a series of connecting north-south parallel ridges. On the north it extends up into the area of the Fortieth Parallel surveys, where it is represented by a series of detached low limestone mountains and finally dies out in the valley.

TOPOGRAPHY.

The Long Valley Range consists in general of a single main ridge, on both sides of which the ascent from the base is comparatively gentle. The interrupted form of the northern end of the range, resulting in detached clumps of hills, has probably been brought about by erosion, which has cut deep into the ridge and formed valleys which were afterwards filled up with detrital material, on a level with that of the main valleys between the ranges. On the eastern side of the south end of the range a great flood of andesitic lava has filled a former valley to a height equal in general to that of the preexisting ridges.

This andesite itself has been considerably eroded. The valleys which have been cut in it, being younger than the main valley into which the lava was poured, are instructive as to the manner of the formation of desert valleys in general and their filling up with detrital accumulations. Each of these narrow valleys in the lava, often only a few hundred feet wide, presents in a small way all the characteristics of the larger valleys which separate the ranges. In the middle is a flat sage-brush plain, and on the sides long gentle slopes of wash proceed from the gullies which cut up the adjoining ridges. In these deposits of the smaller valleys, as in those of the larger valley, there is no trace of deposition in the presence of water, but the valleys have filled up evenly and smoothly with dry material, distributed perhaps in part by rivulets and by wind storms.

SEDIMENTARY ROCKS.

CARBONIFEROUS.

At the south end of the range a section was followed along a portion of the road between Hamilton and Ely. The rock here is a limestone, often cherty or aphanitic. Under the microscope the chert shows cross sections of organic forms. The western edge of the section yielded the following Upper Carboniferous fossils, which were determined by Dr. Girty:

Marginifera muricata?
Productus prattenianus.
Productus inflatus?

Farther east the following Upper Carboniferous fossils were collected from the same limestone at a horizon several hundred feet higher than the above:

Fenestella? sp.
Campophyllum torquium?
Productus prattenianus.
Fusulina cylindrica.
Rhombopora lepidodendroides.
Fistulipora? sp.
Productus semireticulatus.

Only about 1,000 feet of strata are exposed in this section, owing to the low dip of the rocks.

On the north end of the range the separated groups of low mountains above mentioned appear to be almost entirely composed of Carboniferous limestone. They are so shown on the maps of the Fortieth Parallel Survey. The writer collected two lots of Upper Carboniferous fossils at the northern end of the limestone mountain which lies just east of Franklin Lake and the northern end of Ruby Lake. This is practically the northern terminus of the Long Valley Range, although in the Fortieth Parallel maps it is given under the head of the Ruby Group of Mountains.

According to Dr. Girty's determination, the first locality yielded *Marginifera splendens?*

The second locality afforded the following:

Chonetes flemingi.
Productus subhorridus.
Productus multistriatus.
Spirifer cameratus?
Spiriferina pulchra.
Seminula mira.

South of the lava area which fills the valley between the Long Valley Range and the Egan Range, on the road from Hamilton to Ely, there is a narrow spur of mountains running from the neighborhood of Summit stage station to the Egan Range, south of Ely. This may be considered as an outlying spur of the Egan Range, but yet may extend beneath the lava and so form a connection with the Long Valley Range. From the rocks of this spur at a point just south of Summit station a Devonian coral was obtained. Farther south in the same ridge are Carboniferous fossils, as described under the head of the Egan Range (see p. 51).

IGNEOUS ROCKS.

LAVAS.

The great mass of lava which flanks the eastern side of the Long Valley Range proper at its lower end has already been mentioned. The extent of this patch of lava to the north is uncertain, but probably is not more than 10 or 15 miles. To the south it passes under the Pleistocene accumulations of Sierra Valley, while to the east and to the west it abuts against the limestones of the Egan and the Long Valley ranges. As noted above, this lava has been considerably eroded. Thin sections of the rock show it to be in general a dacite-andesite, the prevalent type being a dacite containing augite, biotite, and hornblende.

STRUCTURE.

FOLDING.

A section taken at the southern end of the range shows a mono*clinal structure for the* main ridge. In reality, however, this is the

east side of an anticline whose axis lies in a narrow valley to the west of the main ridge and whose easterly limb is exposed in the next ridge to the west (see fig. 1, p. 66).

The spur of Devonian-Carboniferous rocks described on page 56 is separated from the main ridge by Pleistocene deposits and by lava, and the structural connection is not shown, but in itself it exhibits a series of somewhat closely compressed regular open folds with north-south strike, changing to a northwest-southeast strike as the spur approaches the Egan Range. In this minor ridge there is exposed, beginning with the most westerly fold, an anticline, a syncline, a second anticline, and a second syncline.

For the main ridge of the Long Valley Range the general strike is seen to be parallel to the general trend of the mountains; that is, a little east of north. At the north end of the range, at the fossil localities, a slight syncline with a general north-south strike was observed in the Carboniferous limestone.

GOLDEN GATE RANGE.

The Golden Gate Range scarcely deserves a separate name, on account of its comparative insignificance. This name is applied to a connected series of low mountains which lies to the east of the Grant Range, and properly has a north-south extent of not more than 25 miles, with an average width of 3 or 4 miles. On the south the Golden Gate Range is connected by low hills with the northern extension of the Hiko Range, while on the north the range dies away into the Sierra Valley. Twenty-five miles north of the north end of the range there is a chain of low hills running north and south and lying midway between the White Pine Range and the Egan Range. These hills might perhaps be considered as the northern continuation of the Golden Gate Range, the intervening portion being covered up by the Pleistocene accumulations of Sierra Valley.

TOPOGRAPHY.

The mountains which make up the Golden Gate Range are entirely detached from one another, and are separated by narrow stretches of Pleistocene valley deposits, on a general level with the valleys on both sides of the range. The separate groups are sometimes composed of stratified rocks and sometimes of lava. The hills of stratified rock are scarped along the axes of anticlinal folds. They are therefore scarped on both sides when they are synclinal, while when they are anticlinal they have in general smooth sides with a sharp downcutting in the center. The groups which are composed of volcanic rocks have naturally a milder and more uniform topography.

SEDIMENTARY ROCKS.

SILURIAN.

An isolated butte at the northern end of the Golden Gate Range, not very far from Adams's ranch on White River, exposes a very inter-

esting section of Silurian rocks. The beds here strike N. 35° W. and dip 30° NE. At the base of the section is 300 feet of thin-bedded, somewhat fetid limestone and limy shale. Above comes 250 feet of white vitreous quartzite, which is undoubtedly the Eureka formation. Above this comes about 800 feet of comparatively massive brownish limestone (the Lone Mountain formation). At a point about 150 feet below the bottom of the Eureka quartzite, in the Pogonip limestone, Ordovician fossils were found. They have been determined by Dr. Girty as follows:

Orthis perveta.
Maclurea sp.
Murchisonia sp.
Pleurotomaria sp.
Leperditia bivia.
Illaenus sp.
Trilobites undet.

DEVONIAN.

Southwest from this butte and about 10 miles distant is a considerable clump of hills, which forms one of the chief features of the range. A section of about 2,000 feet of limestone is here exposed. The lower 1,000 feet is of limestone, which in places has the peculiarity of weathering brown and craggy, like quartzite. The upper 1,000 feet is composed of shale and thin-bedded limestone. In the lower limestone, where it was examined, the rocks are chiefly composed of corals and constitute, therefore, part of a Devonian coral reef. The same reef, with the same corals, was found in the ridges which form the southern continuation of the Egan Range, 12 or 15 miles east of here. The following Devonian fossils were identified by Dr. Girty:

Amphipora? sp.
Stromatoporoid coral.
Indeterminable gasteropod.

PLEISTOCENE.

As before noted, the hills of the Golden Gate Range are surrounded and often separated by accumulations of Pleistocene material. This material is generally angular and bears the marks of having been brought to its present position by the influence of rains, wind, and gravity, not by stream or lake action. Probably this Pleistocene forms a veneer over underlying Tertiary deposits, as is the case in the next valley to the west—Railroad Valley.

In the neighborhood of the Silurian butte above mentioned is an extensive deposit of calcareous hot spring tufa, covering apparently an area of several square miles and eroded into hills and bluffs in places 40 feet high. Within this area active hot springs are plentiful.

IGNEOUS ROCKS.

Several of the eminences of the Golden Gate Range are composed *of volcanic rocks*, which also surround some of the hills of stratified

rocks and apparently extend to the east to the southern end of the Egan Range, as represented on the map. A specimen of the lava from the north end of the Golden Gate Range proved to be quartz-latite.

STRUCTURE.

FOLDING.

In the stratified rocks of the Golden Gate Range the strike runs diagonally or transversely to the general trend of the mountains. It has been noted how in the southern part of the Schell Creek and Egan ranges the folds have northeast and southwest axes, which are diagonal to the general trend of these ranges. In the Pahroc Range the trend of the axes of folding seems to be north and south, parallel with the mountains. Between the Pahroc and the Egan ranges there is an area containing a number of minor cross folds, which have a curving axis and which extend to and connect with the folds of the Golden Gate Range. Several of these minor folds seem to die out just west of the Golden Gate Range.

The anticlinal fold which marks the rocks of the northernmost and chief group of hills of the range in which the Devonian corals were found may be a continuation of a possible broader anticlinal axis running between the Worthington Mountains and the northern end of the Hiko Range. The folds of the Golden Gate Range lying south of this anticline, comprising two more anticlines with intervening synclines, do not have any visible relation to the folds to the west or south. However, they may be traced continuously to the east across the several ridges which mark the southern end of the Egan Range. The southernmost folds curve around southeasterly toward the Pahroc Range, while the northerly ones, diverging from the others, maintain a northeasterly direction.

FAULTING.

In the neighborhood of the Silurian butte above mentioned the abundance of hot springs suggests the presence of faults, but this could not be established.

HUMBOLDT RANGE.

The Humboldt Range is the most important mountain ridge in the Great Basin between the Wasatch and the Sierra Nevada. Its southern end only was visited by the writer, and as this has already been mapped and explored by the geologists of the Fortieth Parallel Survey, it is unnecessary here to go into details. But inasmuch as the writer collected fossils in localities from which none had been reported, it is thought advisable to insert this short description.

TOPOGRAPHY.

North of Fremont Pass the Humboldt Range is exceedingly rugged and precipitous. South of the pass the mountains become lower.

At Hastings Pass they are of only moderate height, and the ascent from the base on both sides to the summit is not precipitous. South of Hastings Pass the mountains are still lower, and pass into straggling groups which connect with the northern extension of the White Pine Range.

SEDIMENTARY ROCKS.

North of Fremont Pass the Humboldt Range consists mainly of Archean rocks, as has been described by King[a] and Hague.[b] These rocks consist of a series of gneisses and schists overlying the basal granite and having a thickness of 8,000 or 10,000 feet. Of this series the lower 5,000 feet is in general a mica-gneiss, while the upper 5,000 feet is a hornblendic and dioritic schist, containing veins of quartzite. At the top are beds of limestone and quartzite. Above this gneiss and schist series comes a series of quartzites about 2,000 feet thick. The quartzites are white or yellow-brown in color and contain secondary garnet, hornblende, actinolite, muscovite, biotite, and iron oxide. On them rest unconformably the Paleozoic strata, with the Devonian generally at the base and the Carboniferous above.

King notes the resemblance of the quartzite series (which lies unconformably beneath the Paleozoic beds) to similar rocks in the Wasatch Mountains. It is possible also that the thick white and brown Cambrian quartzites exposed in the Snake Range, especially in the vicinity of Jeff Davis or Wheeler Peak, may be equivalents of the Humboldt quartzite.

South of Fremont Pass the eastern face of the range is composed of easterly or southeasterly dipping limestones. At a point not more than 4 miles south of the pass the following Coal Measures fossils were collected by the writer from a butte at the base of the mountains. They were determined by Dr. Girty as follows:

Fistulipora sp.
Campophyllum torquium?
Lophophyllum proliferum.
Rhipidomella pecosi.
Productus sp.
Spirifer cameratus.

These same limestones continue all along the east face of the range as far as Hastings Pass. On the summit of the pass is found a considerable thickness of sandstones mixed with fine conglomerates. These the Fortieth Parallel geologists regarded as Devonian of the Ogden formation, which would correspond to the Diamond Peak quartzite of the Eureka section. A short distance west of the summit the Paleozoic rocks are overlain unconformably by thick deposits belonging to the Humboldt Pliocene of the Fortieth Parallel Survey. At the upper edge of the Pliocene deposits the material consists of

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[a] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 62. [b] Idem, Vol. II, p. 528.

large angular fragments of limestone. From some of the largest of these fragments fossils were obtained which were determined by Professor Ulrich as Ordovician.

Leperditia bivia White.
Leperditia sp. (nevadensis?).
Rhynchonella?
Strophomena minor Walcott.
Strophomena? nemea H. & W.?
Dalmanella perveta? Walcott.
Bathyurus.

If Silurian rocks exist in place at this point one may well suppose that they are exposed by means of a fault, for otherwise the thickness of strata in the mountains seems hardly sufficient to account for their appearance.

IGNEOUS ROCKS.

North of Fremont Pass the basal rock appears to be mica-granite, as described by King.[a] South of Hastings Pass a considerable area is also represented as granite in the Fortieth Parallel maps.

STRUCTURE.

FOLDING.

The general structure of the Humboldt Range is a broad anticline, as has been mentioned by King[b] and by Hague,[c] and as can be seen by an inspection of the maps of the Fortieth Parallel.

FAULTING.

It appeared to the writer that Fremont Pass is the line of an east-west fault, and that this explains the abutting of the Paleozoic rocks on the south against the granite and Archean on the north. Moreover, the above-mentioned Paleozoic rocks are sharply turned up along this supposed fault line, so that they dip steeply, and their strike swings round from the normal north-south direction to a northeasterly one, so as to be nearly parallel with the supposed fault.

The possible existence of a fault along the west side of Hastings Pass exposing the Silurian rocks has been mentioned above.

WHITE PINE RANGE.

The White Pine Range, as here described, is the southern continuation of the Humboldt Range, and its northern end begins about 10 miles south of Hastings Pass, in that range. From this point it extends unbroken southward for 100 miles, with a general due north-south trend. At its southern end it is continuous with the short Grant Range, which topographically and geologically is a part of it, but which is differently named and will be described separately.

[a] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 64. [b] Ibid., p. 183. [c] Idem, Vol. II, p. 528.

TOPOGRAPHY.

The northern part of the White Pine Range, from the southern end of the Humboldt Range to the White Pine mining district, consists of a main ridge, which is narrow and not very high, with a number of minor ridges on each side, separated from the main ridge by narrow valleys in which the underlying rock is only partly obscured by Pleistocene detritus. In the vicinity of the White Pine mining district the mountains grow higher and the small north-south ridges change into a complicated group of irregular mountains. At the same time the main ridge broadens out to four or five times its former width.

In the White Pine mining district three main north-south ridges may be distinguished—that of Pogonip Mountain on the west, the minor one of Treasure Hill in the middle, and that of Mokeamoke Ridge on the east. Still farther east a succession of regular north-south ridges, similar to those just described for the northern part of the range, form a continuation of the southern end of the Long Valley Range.

Within the White Pine mining district the mountains reach a height of 10,000 feet above the sea, while to the north and to the south they are considerably lower. To the south of the district also the mountains assume something of the same simple character as they do to the north, being made up of regular north-south ridges, and for the most part consisting of a single main ridge. While in the mining district the mountains and valleys are irregular, the topography of the range to the north and to the south is quite conventional, showing a uniform succession of serrated peaks of nearly uniform height, with their sides furrowed at comparatively regular intervals by the drainage.

Within the mining district the irregularity is due, as will be presently seen, to the local complexity of the geologic structure. Pogonip Mountain, which, near Hamilton, juts boldly out from the main ridge and is the highest peak in the whole neighborhood, has a bold scarp to the north and to the west. Throughout the district there are a number of other precipitous cliffs. But in the rest of the range the mountains show the same steep, but yet not abrupt, faces that are characteristic of the other ranges of the region. It was noticed, however, that south of Hamilton the west face of the mountains was rather steeper than the eastern one.

SEDIMENTARY ROCKS.

CAMBRIAN.

Pogonip Mountain is composed of Paleozoic strata which dip in general toward the east, forming the western limb of the syncline *whose eastern limb* is exposed on the west side of Treasure Hill Ridge.

On the western side of Pogonip Mountain Mr. Walcott[a] has determined from fossils the existence of the Cambrian Hamburg limestone of the Eureka section. About 800 feet of the Cambrian is exposed at this point.

SILURIAN.

Silurian rocks were described from Pogonip Mountain by Mr. Hague[b] during the Fortieth Parallel Survey. Later on the Silurian beds were also visited and reported upon by Mr. Walcott.[c] Mr. Walcott found in Pogonip Mountain the following formations, divided according to the Eureka section:

Section at Pogonip Mountain.

	Feet.
Lone Mountain limestone	1,450
Eureka quartzite	350
Pogonip limestone	5,200

The writer obtained from Mr. Grandelmeyer, of Hamilton, a fossil said to come from a locality about 6 miles south of that place. It was identified by Dr. Girty as *Receptaculites* sp. and assigned to the Ordovician.

DEVONIAN.

While Pogonip Mountain is composed almost entirely of Silurian strata, the ridge next east is made up almost entirely of Devonian. Mr. Hague has described the strata and their contained fossils at this point. The formation, divided according to the Eureka section, comprises the Nevada limestones and the White Pine shales. Besides this Devonian ridge, the writer has also recognized the White Pine Devonian on the east side of Mokeamoke Ridge, where it is repeatedly brought to the surface beneath the Carboniferous rocks by the erosion of anticlinal folds. He has moreover traced it north of the White Pine mining district for some distance along the west side of Mokeamoke Ridge, where it is largely hidden by Pleistocene detritus.

CARBONIFEROUS.

The third and most easterly of the three ridges at White Pine, Mokeamoke Ridge, is made up chiefly of Carboniferous rocks which carry abundant fossils. A list of Carboniferous fossils obtained from Mokeamoke Ridge in the mining district is given by Mr. Hague.[d] The writer has traced the continuation of the Carboniferous belt of Mokeamoke Ridge 15 or 20 miles north of the mining district. At a

[a] Mon. U. S. Geol. Survey Vol. XX, p. 191.
[b] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 542.
[c] Op. cit., p. 191.
[d] Op. cit., p. 547.

point 6 miles north of Hamilton Upper Carboniferous fossils were collected. The following were determined by Dr. Girty:

Productus semireticulatus?
Spirifer boonensis.
Seminula subtilita?
Euomphalus sp.

In the same rocks, close by the above locality, but at a horizon about 200 feet higher up, were found the following:

Productus prattenianus.
Productus sp.
Spirifer boonensis.
Seminula subtilita.

The minor parallel ridges which mark the northern end of the range have all the aspect and structure of the Carboniferous limestones. The writer has also found Upper Carboniferous limestones lying directly north of Pogonip Mountain, being separated from the Silurian rocks at this point by a heavy east-west fault which determines the northern end of this mountain. Here the following fossils were collected:

Lithostrotion? sp.
Productus sp.
Spirifer boonensis.
Spiriferina gonionotus.
Seminula mira?
Bulimorpha chrysalis?

On the eastern side of Mokeamoke Ridge the writer has traced the Carboniferous rocks continuously across the intervening ranges to the southern end of the Long Valley Range.

At the head of Allepaw (Applegarth?) Canyon, which is on the east side of the range, just east of Hamilton, *Glyphioceras* sp., an Upper Carboniferous form, was found.

Half a mile farther east, down the canyon, were found the following Upper Carboniferous fossils: *Marginifera muricatus*, *Productus semireticulatus*, *Productus prattenianus*.

Still half a mile farther, at the old pumping station for the town of Hamilton, were found: *Orbiculoidea* sp., *Productus semireticulatus*, *Productus prattenianus*, *Marginifera muricata?*

Along this section the Carboniferous rocks alternate with narrow belts of the underlying Devonian, which is exposed by the erosion of the anticlinal folds.

The Carboniferous section here has always at the base the Diamond Peak quartzite of the Eureka section. This quartzite, or rather sandstone (for it is not actually a quartzite), outcrops all along the western base of Mokeamoke Ridge, so far as this has been followed, and has a thickness of several hundred feet—much smaller than at Eureka. Above the sandstone come heavy, blue limestones containing Coal

Measures fossils. In the Carboniferous hillocks at the northern base of Pogonip Mountain conglomerates were found containing pebbles of red and purple chert, closely resembling similar beds just west of here, on the east side of the Pancake Mountains.

RHYOLITE ASH.

North of the White Pine mining district and on the western side of Mokeamoke Ridge, the broad area of low hills is partly covered by a deposit of stratified rhyolitic ash. Near Sixmile House, 6 miles north of Eureka, a dike of rhyolite is found which cuts this deposit and shows that the ash is the earlier of the two. It is very likely that this rhyolite ash is of the same age as that exposed at Twin Springs in the Pancake Range.

IGNEOUS ROCKS.

LAVA.

The existence of a rhyolite dike in the vicinity of Sixmile House has just been referred to. In this neighborhood and farther north one finds, together with the rhyolite ash already described, numerous small buttes of lava which have been eroded into separate patches, but which once evidently were joined together to form a continuous thin sheet which spread over this region.

GRANITE.

Small patches of coarse-grained hornblende-granite have been mentioned by Hague[a] as outcropping along the base of Pogonip Mountain. Whether this granite is intrusive or Archean is not stated.

STRUCTURE.

FOLDING.

The main ridge, Mokeamoke, which extends north from the White Pine mining district, has a general synclinal structure. This syncline is variously affected by erosion, so that at times one limb is almost completely worn away, giving the range the aspect of being monoclinal. For the most part, however, this syncline is well shown for a number of miles north of Hamilton. Still farther north, as far as the southern end of the Humboldt Range, the structure was not carefully observed, but in general it consists of a series of gentle open folds trending parallel to the mountain ridges. On Coal Burners or Bald Mountain the attitude of the strata seems to be very near horizontal.

Besides the main Mokeamoke Ridge, whose structure, as sketched about 8 miles north of Hamilton, is shown in the accompanying figure

[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 542.

(fig. 1), there are several minor parallel ridges. North of the White Pine mining district these minor ridges lie east of the main one, forming a continuous section which unites Mokeamoke Ridge with the

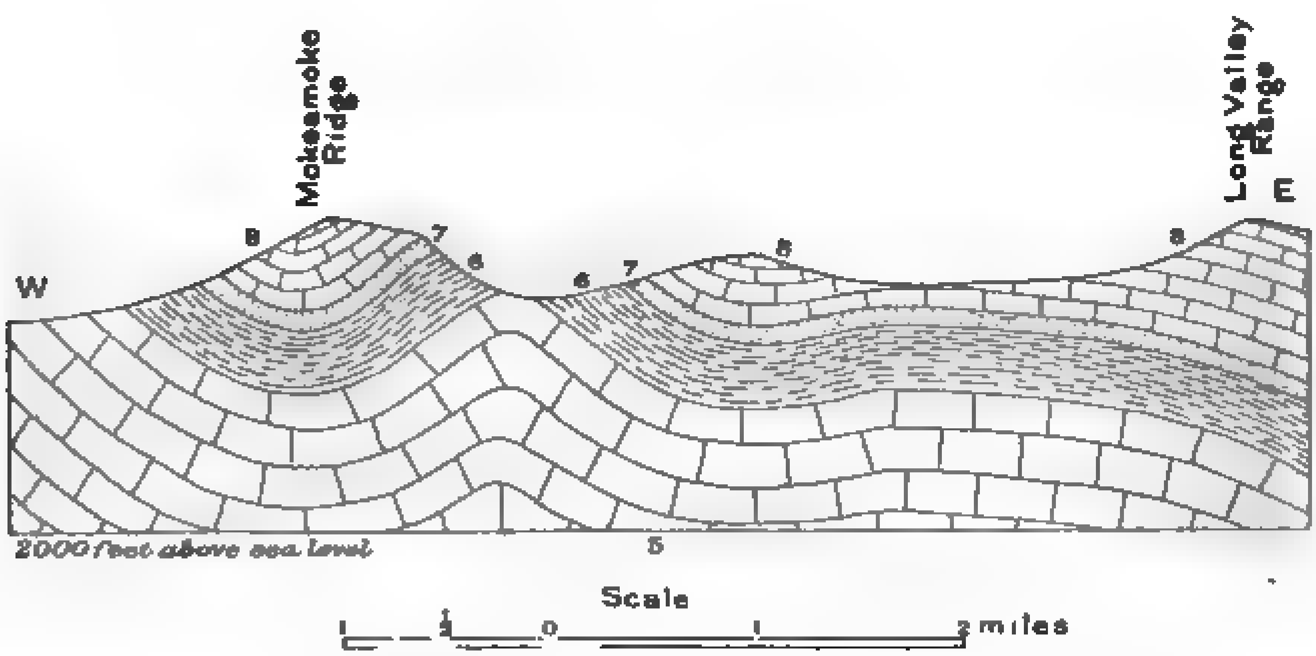

FIG. 1.—Sketch section 5 miles north of Hamilton across White Pine Range to the eastern edge of Long Valley Range. (For explanation of numbers see fig. 2.)

southern end of the Long Valley Range. These ridges and the accompanying valleys (in whose bottoms the rock is very little obscured by

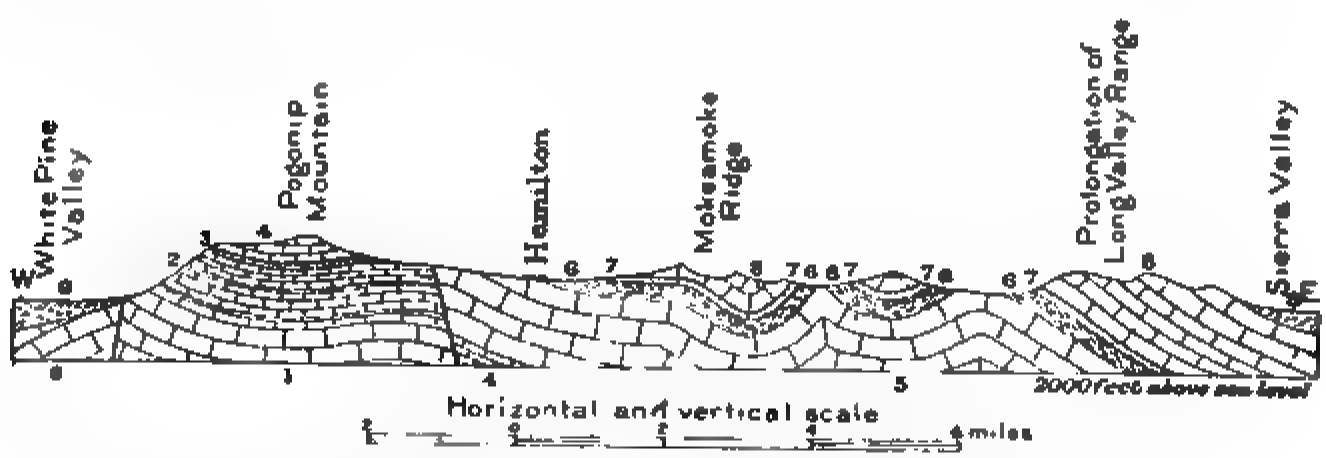

FIG. 2. Sketch section through White Pine Range at Hamilton at the junction of White Pine and Long Valley ranges.

1. Cambrian limestones.
2. Pogonip limestone (Silurian).
3. Eureka quartzite (Silurian).
4. Lone Mountain limestone (Silurian).
5. Nevada limestone (Devonian).
6. White Pine shale (Devonian).
7. Diamond Peak quartzite (Coal Measures).
8. Coal Measures limestone.
9. Valley wash (Pleistocene).

detritus) expose a series of gentle anticlinal and synclinal folds of similar character to the syncline of Mokeamoke Ridge. The structure here is shown in fig. 2.

FAULTING.

In the region of Hamilton, where the mountains widen out noticeably, the structure of the rocks west of Mokeamoke Ridge consists in general of a pronounced north-south trending anticline, which affects the central ridge comprising Treasure Hill and minor eminences, and, further west, a general syncline, the western limb of which is Pogonip

ridge. Within this region also there are a great number of faults, which appear in general to belong to two systems, one having a north-south and the other an east-west strike. The heaviest fault of the region appeared to the writer to be that at the northern end of Pogonip Mountain, where the Coal Measures limestones are brought by a hidden east-west fault directly against the Silurian strata of the mountain. This fault, therefore, must have a vertical displacement of from 7,000 to 10,000 feet. On the northwest corner of Pogonip Mountain another fault was observed, having a considerably less displacement and a northwest strike. Mr. Hague[a] mentions another heavy fault on the western side of the same mountain. Between Pogonip Mountain and the Treasure Hill ridge there is also, according to Mr. Hague,[b] a displacement. In Treasure Hill itself Mr. Hague[c] described, and the writer subsequently observed, an east-west fault which crosses from the southern side of Treasure Hill to Pogonip Mountain. It appeared to the writer also that the steeply bent anticlinal fold which is exposed in an east-west cross section of Treasure Hill has been faulted somewhat along its axis and the eastern part relatively downthrust, the fault being probably a normal one. There are certainly many other faults in the mining district, but all the examinations thus far made have been cursory. On the western side of Mokeamoke Ridge and in Allepaw (Applegarth?) Canyon a number of probable east-west faults were observed.

It will be noted that this faulting is, so far as observed, restricted to the neighborhood of the mining district. To the north and to the south there is little reason for believing that the mountains are much affected by faulting. The White Pine district, then, bears exactly the same relation to the rest of the White Pine Range as the Eureka district does to the Diamond Range. Both are areas of local and special dynamic disturbance, resulting in folding, faulting, and ore deposition, and in both the special effects die out in a surprisingly short distance.

RELATION OF TOPOGRAPHY TO STRUCTURE.

In the northern part of the White Pine Range, north of the mining region, there is a distinct tendency toward anticlinal valleys and synclinal ridges. The mountains, therefore, though determined primarily by erosion, yet have the location of their ridges and valleys governed by the position of the folds. South of the White Pine mining region the same general peculiarities hold to the southern end of the range.

Within the mining region itself the faults introduce a new feature into the topography. The whole district, as before stated, is traversed

[a] Mon. U. S. Geol. Survey Vol. XX, p. 190.
[b] Ibid., p. 192.
[c] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 412.

by a north-south and an east-west system of faults, with minor diagonal ones. Some of these are attended by steep scarps.

In the same district where these scarps occur the folds seem to have directly determined the topography. The Treasure Hill ridge is anticlinal and the valley between it and Pogonip Mountain synclinal. But Mokeamoke Ridge and the ridges to the west are synclinal, with anticlinal valleys, indicating a long-continued erosion period. The folding of the ridges to the west of Mokeamoke Ridge was then distinctly later than that of the ridge itself and later than that of the range in general.

The faults of the mining district appear to belong also to the same recent epoch as the associated folds. Those of Treasure Hill have apparently been affected very little by erosion, and are marked by scarps which seem to represent very closely the vertical displacement. The same seems to be true of the heavy fault which forms the northern end of Pogonip Mountain, which has already been mentioned.

ORES.

The structurally complicated region around Hamilton has been the site of rich ore deposition. The ores are distinctly connected with the fault fissures and have formed largely in their vicinity. Mr. Hague[a] describes the occurrence of the silver deposits of Treasure Hill as (1) in fissures, striking east and west; (2) in deposits between the limestone and shale; (3) in beds or chambers in the limestone and parallel to the stratification of the rock; and (4) in the regular seams or joints across the rock bedding, most frequently with a north-south trend. The minerals found in the mining district comprise quartzite, calcite, gypsum, fluorite, barite, black oxide of manganese, rhodochrosite, cerargyrite, galena, cerussite, and azurite. The district once had a population of many thousand, but at present there is very little activity.

QUINN CANYON AND GRANT RANGES.

The Grant Range is really the southern extension of the White Pine Range, there being no decided break between the two. It has a length from north to south of about 30 miles. The Quinn Canyon Range is closely connected with the Grant Range, being separated only by a narrow rock-cut valley, whose bottom is for the most part comparatively free from detritus. It is, however, offset from the Grant Range to the west. The Quinn Canyon Range is broad and short, having a north-south extent of about 25 miles, and an east-west extent of nearly 20 miles.

TOPOGRAPHY.

The Grant Range consists of a single main ridge, rather flat and broad on top, and cut up deeply by the smaller mountain valleys,

[a] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 418

which run out into the wide detritus-filled main valleys. These smaller valleys and their auxiliary gulches are generally bounded by steep walls. In general, the main mountain fronts, on the east and west, are also steep. The south end of the range, which lies just east of Garden Valley, decreases gradually in height, and so passes into a series of low buttes which run out into the valley.

The Quinn Canyon Range is bounded by steep cliffs on the east, west, and north sides of its northern half, and the small valleys and ravines which have been worn in this half are guarded by the same precipitous walls as in the Grant Range. This part of the range is cut out of limestone; hence its rugged and irregular topography. The southern part of the range is a mass of volcanic rocks, which, however, have been extensively eroded. The type of topography is naturally quite different from that in the limestone region, the distribution of the valleys being regular and the rocks being cut up into steep but not precipitous mountains. The southern end of the range also appears to have a more gradual descent into the plain that has the northern.

SEDIMENTARY ROCKS.

CAMBRIAN.

In the foothills at the north end of the Quinn Canyon Range and to the north of the abrupt scarp which limits the northern end of the mountain proper an exposure of rusty-brown shaly limestone was found in a canyon, from which fossils were collected. They were determined by Mr. Walcott as Cambrian.

These were the only Cambrian rocks found in the two ranges. Immediately to the south, in the high mountains of the Quinn Canyon Range, the rocks are Silurian and probably also Devonian, and indeed an outcrop of undoubtedly Silurian quartzite (Eureka formation) was found only a short distance east of the Cambrian locality. The attitude of the beds in both outcrops makes it clear that between the two there is a heavy fault, and from the lack of faulting in the Quinn Canyon Range proper it is clear that the fault does not run in a north-south direction, but must run in a general east-west direction, not far from the base of the heavy scarp which delimits the mountain at its north end.

SILURIAN.

On the steep west face of the northern end of the Quinn Canyon Range the mountains near the base consist of massive, often shaly, dark-blue to gray-blue limestone, much broken and veined as a consequence of granitic intrusions. On account of the alteration the organic remains obtained from this limestone are not identifiable. Six hundred or 800 feet above the base of the limestone, as exposed, comes about 200 feet of hard white vitreous quartzite, which one at once recognizes as probably the Eureka formation. Above this quartzite comes upward of 4,000 feet of gray-blue extremely massive limestone, extending to the top of the mountain and weathering into

smooth, perpendicular, pinnacled cliffs. This same limestone was found all along the north end of the mountain scarp, and also forms the precipitous cliffs on the east side of the mountain front, opposite the Grant Range.

In some low foothills on the northern slope of this range, facing Railroad Valley, the following Ordovician fossils (determined by Professor Ulrich) were found by Mr. F. B. Weeks[a] in 1900:

Girvanella sp. undet.
Orthis n. sp. (cf. O. holstoni Safford).
Dalmanella perveta.
Orthis tricenaria?
Cf. Strophomena nemea H. & W.
Zygospira n. sp. A large species, ½ inch or more wide.
Three undetermined brachiopods, possibly referrable to Platystrophia.
Orthodesma sp. undet.
Lophospira.
Cf. Pleurotomaria lonensis Walcott.
Orthoceras.
Leperditia (near L. fabulites Conrad).
Leperditella sp.
Primitia (near P. celata Ulrich).
Bathyurus (1).
Bathyurus (2).
Bathyurus (3).

Within the main range, on the slopes of Big Creek, in the northwestern part of the range, the following Ordovician fossils were collected by Mr. Weeks, determined by Professor Ulrich:

Receptaculites mammilaris Newberry.
Receptaculites ellipticus Walcott.
Plates of a large Carabocrinus similar to one occurring in shales of Black River age of Minnesota.
Plates of Carabocrinus ? with pustulose surface.
Monotrypa sp. undet.
Batostoma sp. undet.
Orthis n. sp. (near O. holstoni Safford).
Orthis pogonipensis H. & W. (cf. O. perveta).
Orthis tricenaria Conrad (small form).
Orthis lonensis ? Walcott.
Maclurea sp. undet. (near M. bigsbyi).
Gyronema sp. nov. (near G. semicarinatum Salt. sp.).
Gen. et sp. nov. (related to Oxydiscus and Conradella).
Orthoceras (small species).
Endoceras sp. undet. (with "Colpoceras" type of siphuncle).
Leperditia n. sp. (semipunctate).
Leperditia n. sp. (elongate bivia).
Leperditella sp. (near germana Ulrich).
Leperditella sp. with ventral swelling in left valve.
Schmidtella n. sp. (near S. crassimarginata).
Aparchites sp. undet.
Tetradella ? sp. nov.
Cranidia and pygidia of six (? 5) species of Trilobites.

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[a] Personal communication to the writer.

On the east side also the Eureka quartzite again appears and can be continuously traced for long distances, thus becoming an important aid in the study of thė stratigraphy. In the valley which separates the Quinn Canyon Range from the Grant Range the Eureka quartzite outcrops on both sides, on the two limbs of an anticlinal fold from which the valley has been eroded. In the bottom of the valley, beneath the quartzite, is found massive limestone, brecciated, hardened, and altered. In the upper part of that portion of the valley draining north (which is separated by a decided divide from that portion which drains to the south into Garden Valley) the ascent takes one above the horizon of the Eureka quartzite into that of the overlying limestones. Along the course of this northern part of the valley no good fossils could be found in any locality, but fragments picked up at various points in the canyon have been identified by Professor Ulrich as Silurian.

Batostoma? sp. undet.
Bathyurus? sp. undet.
Leperditella? sp. undet. Two species.
Orthis sp. (near O. holstoni Safford).
Orthis sp. (near O. tricenaria).
Receptaculites ellipticus Walcott.

At the divide above mentioned the stratified rocks are hidden by later volcanics. A short distance south of the pass, however, the Eureka quartzite is again encountered, and above it the same heavy limestone as appeared in the Quinn Canyon Range. These rocks extend quite through to the eastern face of the Grant Range. On the lower part of Cherry Creek, after passing the volcanic area, dense blue limestone is encountered, and farther down the Eureka quartzite. From the limestone beds, a few hundred feet below the quartzite, the following Ordovician fossils were obtained and determined by Professor Ulrich.

Eccyliopterus sp. undet.
Encrinurus sp. undet.
Isotelus?.
Lingula sp. undet.

The Eureka quartzite, dipping to the east, forms the eastern front of the Grant Range for some miles north of Cherry Creek, and then, on account of the irregular erosion of the mountain front, passes into the foothills, where it can be traced for a number of miles farther north.

DEVONIAN.

No Devonian fossils were obtained from either the Quinn Canyon or Grant ranges. As already noted, however, the thickness of the limestone section which is exposed above the Eureka quartzite is upward of 4,000 feet in both ranges. In the Eureka section[a] the thickness of the Silurian Lone Mountain limestone above the Eureka quartzite is

[a] Mon. U. S. Geol. Survey Vol. XX, p. 13.

given at 1,800 feet. There is an unconformity at Eureka between the Eureka quartzite and the overlying limestone. Nevertheless, it is very likely that the upper portion of the massive limestone observed in the Quinn Canyon and Grant ranges includes part of the Devonian limestone of the Nevada formation.

CARBONIFEROUS.

On the eastern slope of the Grant Range, north of Warm Spring, in White River Valley, the following Carboniferous fossils were collected by Mr. F. B. Weeks[a] and determined by Dr. Girty:

Chonetes sp.
Chonetes illinoisensis.
Derbya kaskaskiensis.
Productella ? near concentrica.
Spirifer centronatus.
Camarotœchia sp.
Eumetria verneuiliana.
Naticopsis sp.
Ostracoda.

PLIOCENE.

In the northern part of the valley separating the two ranges there are found, up to a height of 6,200 feet above the sea, horizontally bedded arkoses and conglomerates, made up of the fragments of the limestone cliffs above and nevertheless hardened into solid rocks. This may be a shore formation, and may belong to the Pliocene lake whose sediments are shown in the Pancake Range at Twin Springs and at Hot Creek. The Pleistocene subaerial accumulations hide the Tertiary strata throughout the greater part of the valleys. A hint of the former existence of a Pliocene lake on the west side of Quinn Canyon Range, however, was found in the peculiar development of the gulches which furrowed the volcanic rocks. These gulches are deepest at the top, and grow progressively shallower lower down, until near the bottom they die out entirely. This may signify that the development of the gulches began above the surface of the Pliocene lake and as the lake became lower the gulches were forced to extend themselves, but naturally accomplished only a small amount of cutting in those new portions as compared with the long-established upper parts.

IGNEOUS ROCKS.

RHYOLITE AND GRANITE.

On the west side of Quinn Canyon Range, directly east of Twin Springs, are found great masses of siliceous igneous rocks which widen in extent farther south and cover up the whole of the range.[b] At the northern end of the mountain valley which separates the most easterly part of the range from the westerly part, along which the Quinn Canyon

[a] *Personal communication to the writer.*
[b] *G. K. Gilbert, U. S. Geog. Surv. W. One Hundredth Mer.*, Vol. III, p. 122.

road runs, the volcanic rock has been stripped down to the underlying limestone, which is found to be traversed by great dikes of acid rock, varying from coarse to fine in texture. The overlying rhyolite and the dike rocks were examined microscopically. Of two specimens of the dikes one was a coarse biotite-hornblende-granite and the other a very fine biotite-granite-porphyry, the same mineralogically as the coarse variety, but both mineralogically and structurally far more closely connected with the rhyolite.[a] It is probable, therefore, that the dikes and the massive eruptions constitute different parts of the same igneous mass.

BASALTIC VOLCANICS.

In the small valley between the two ranges, thin-bedded basaltic volcanics occur just south of the pass and stretch over a considerable area. These rocks are fine grained or glassy and show very beautiful flow structure, in strong contrast to the massive, rugged rhyolite in the hills above them. Specimens examined microscopically show the rock to be a basalt carrying augite and hornblende. The basaltic rocks extend for some distance along Cherry Valley.

QUARTZ-LATITES.

On the east side of the Grant Range, near the point where it joins the White Pine Range, the outlying foothills which bound the southern or southwestern end of Sierra Valley are evidently composed of dark-colored volcanic rock. This is not far from similar volcanic areas which form the northerly continuation of the Golden Gate Range, and is very likely of the same nature. From one of the volcanic hills of the Golden Gate Range near this point a specimen proved to be quartz-latite, containing augite, biotite, and hornblende.

RELATIVE AGE OF LAVAS.

In these two ranges the rhyolites are distinctly oldest, as shown not only by the fact that the more basic lavas overlie them, but also by the greater erosion of the rhyolites as compared with the others. The latite appears to be of intermediate age. It is probable that the rhyolites and the basalts are to be correlated with the corresponding lavas of the Pancake Range, as exhibited at Twin Springs.

STRUCTURE.

FOLDING.

At the west base of the Quinn Canyon Range the distribution of the Eureka quartzite shows that there exists here an anticline with a north-south or northeasterly-southwesterly axis. The north end of the range exposes a broad, very shallow syncline, which succeeds the anticline to the east. In the center of this syncline the beds are horizontal for a considerable distance, and the maximum dip on

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[a] J. E. Spurr, Variations of texture in certain Tertiary igneous rocks of the Great Basin: Jour. Geol., Vol. IX, 1901, p. 601.

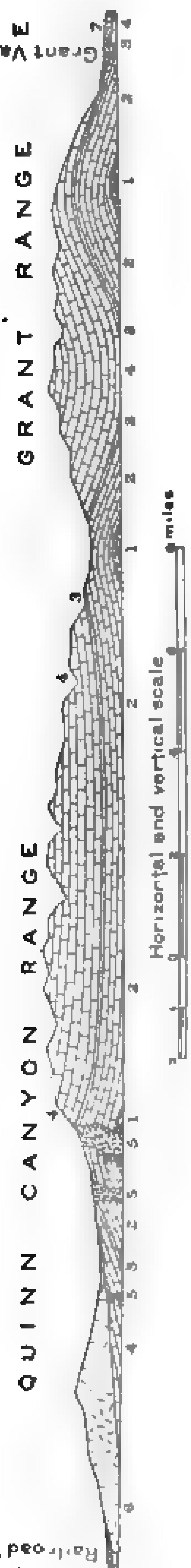

FIG. 3.—Generalized section on a line drawn a little north of east across Quinn Canyon and Grant ranges; at the north end of Quinn Canyon Range, but south of the fault line.

1. Cambrian shales and limestones.
2. Lower Silurian (Pogonip) limestone.
3. Eureka quartzite (Silurian).
4. Massive limestone. At base Silurian (Lone Mountain formation); at top perhaps Devonian (Nevada formation).
5. Granite and granite-porphyry dikes.
6. Rhyolite.
7. Valley alluvium (Pleistocene).

the two sides is about 35°. The syncline is succeeded farther east by an anticline, along which the valley separating the two mountain ranges has been eroded. The Eureka quartzite, which appears on both sides of this anticline, allows its being traced easily for long distances. The fold has a general north-northwesterly trend and is visible in the mountains of the Grant Range about 8 or 10 miles to the northeast of the north end of the Quinn Canyon Range. At this point it is much sharper than farther south.

The eastern limb of the anticline, which is steeper than the western limb, is at the same time the western limb of a syncline which is displayed in the Grant Range. There are some slight minor folds, but the general cross section appears to show a perfect syncline at a point just east of the north end of the Quinn Canyon Range. Farther south, in the vicinity of Cherry Creek, the jutting out of the mountains a little farther east, as a consequence of the irregular erosion, permits the study of a third anticline, which succeeds the syncline, and is a heavy and persistent fold. Looking north from the vicinity of Cherry Creek, one sees this anticlinal fold passing from the side of the mountains into the foothills, so that the strata which at first dip easterly on the mountain face change to a westerly dip, which denotes the eastern limb of the Grant Range syncline. These folds have a more northeasterly strike than those farther west, so that the easternmost anticline just described probably strikes across the valley to the low hills which divide the Golden Gate Range from the Grant Range about 20 miles north of Cherry

Creek, and is again exhibited in the strata of these hills. At this point the anticline is joined on the east by a connected series of open synclines and anticlines, which form the low mountains of the Golden Gate Range and extend across to the northern end of the Hiko Range.

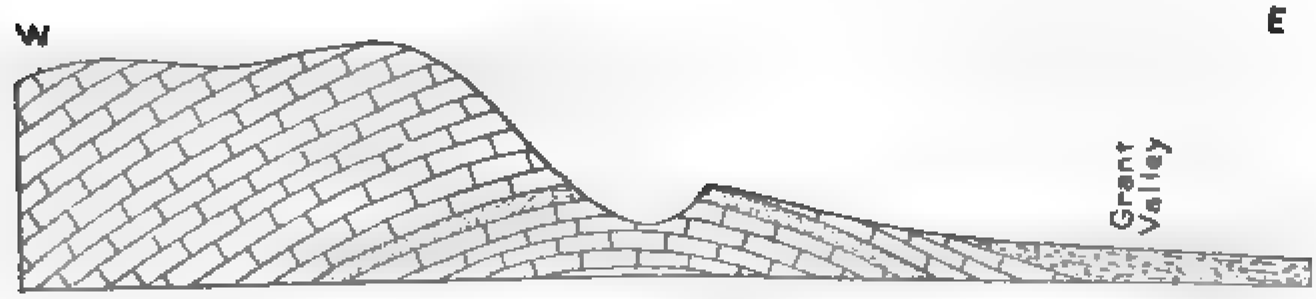

FIG. 4. Sketch section of east front of Grant Range. Taken 5 miles north of fig. 3 and showing altered position of anticlinal fold with reference to the mountain front.

The strikes of these folds become more and more easterly until in the Hiko Range they swing round and become southwesterly, and then, farther south, pass into the usual north-south trend again, having described semicircles. (See figs. 3 and 4.)

FAULTING.

As already mentioned, there is apparently a heavy fault at the northern end of the Quinn Canyon Range, which has brought up the Cambrian rocks on the north side against the Silurian on the south. This was the only fault determined in the two ranges. (See fig. 5.)

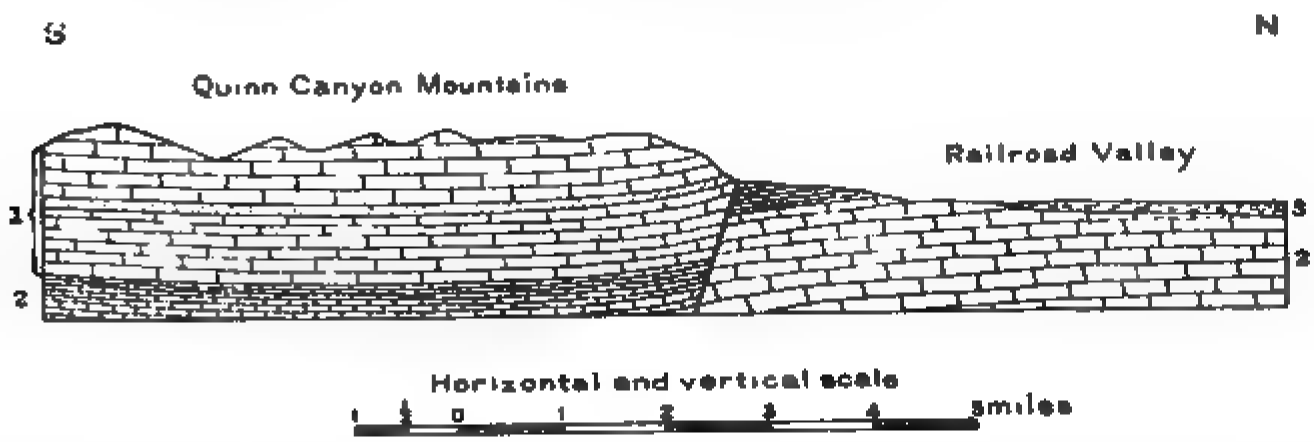

FIG. 5. Generalized sketch section of north end of Quinn Canyon Mountains.

1. Silurian limestones and quartzites (probably Devonian on top).
2. Cambrian limestones and shales.
3. Chiefly Pleistocene valley wash.

Some slight crumpling of the strata was observed on the eastern side of the Grant Range, near Cherry Creek, but this was probably due to the intrusion of the near-by volcanic rocks. In general, the folds of the stratified rocks are even and unbroken.

RELATION OF STRUCTURE TO TOPOGRAPHY.

As described, the Quinn Canyon Range is essentially a simple syncline, as is also the Grant Range. On the west side of the Quinn Canyon Range, the east side of the Grant Range, and also between

the two ranges, are anticlines which are marked by deep depressions. In general, therefore, the form of the mountains is one that implies a long period of erosion subsequent to the folding. Although the faces of both these ranges, on the east and on the west, are somewhat abrupt, the apparent continuation of the beds past these steep faces without break indicates that the faces are not caused by faulting, but are due to erosion. The north end of the Quinn Cañyon Range is probably along a fault, but in this case the Cambrian rocks, which have been relatively upthrust by the faulting, are found in low foothills running into the valley, while the downthrust Silurian rocks form abrupt cliffs facing the Cambrian. It seems, therefore, that if the cliff was primarily determined by faulting it is not directly due to upthrust, but to powerful erosion.

WORTHINGTON MOUNTAINS.

The Worthington Mountains are a very small group lying northwest of the Pahranagat Range, with which they are connected by a series of hills. They also are connected with and probably form the northern extension ef the Timpahute Range, and on the north the rocks are probably continuous with those of the Grant Range, from which they are separated by a few miles of desert valley. On the west side of the Worthington Mountains there is a series of low hills which form a certain connection between them and the Quinn Canyon Range.

Like most of the high mountains of the region, as, for example, the Quinn Canyon Range and the Grant Range farther north, the Worthington Mountains have steep sides, averaging perhaps 30° in inclination to the horizontal, to the east, west, and north.

SEDIMENTARY ROCKS.

The northern end of the range was viewed by the writer from a point several miles farther north. From here the rocks are apparently massive limestones, resembling the Devonian and Silurian strata of the Grant Range just to the north, and having a similar strike. These same strata can be traced southward along the flanks of the mountains. At the northern end, according to Mr. Gilbert,[a] they consist principally of limestone, with some sandstone. The limestone carried abundant fossils, which probably belong to the Silurian.

IGNEOUS ROCKS.

According to Mr. Gilbert, the northern end of the mountain is flanked on the east by beds of rhyolite, associated with which are the Freiberg silver mines.

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 37.

STRUCTURE.

At the northern end of the range the strata dip westerly about 30°, parallel with the general slope of the range. Farther south the dip grows continually less, until at the southern end it is horizontal. It was at this point observed by Mr. Gilbert, who interpreted the horizontal structure of this bold mountain as determined by faults on both sides, the mountain being an upthrust block between the two. Considering the change in attitude between the south and north ends, however, it may also be that the mountain represents part of a fold whose strike diverges slightly from the trend of the ridge.

PANCAKE RANGE.

TOPOGRAPHY.

The northern end of the Pancake Range lies just east of Eureka, where it terminates in White Pine Valley. North of this termination and across the valley is Coal Burner or Bald Mountain, a prominent eminence which appears to be in geologic continuity with the Pancake Range, but which is more closely connected topographically with the southern end of the Humboldt Range. To the south the Pancake Range extends in a straggling fashion as far as Twin Springs, a distance of about 100 miles, with a general trend a little west of south. At Twin Springs a narrow pass separates the Pancake Range from the Reveille Range, farther south. There is, however, no real break in the topographic continuity here, and the distinction is therefore somewhat arbitrary.

The Pancake Range is low and without striking relief, as its name indicates. The northern end of the range consists in part of limestone ridges with general northwest trends, diagonal to the trend of the range. Flanking these limestone ridges are somewhat dissected but nevertheless level-topped volcanic mesas. South of the road between Eureka and Hamilton is a considerable area of shaly Devonian rocks, which are eroded into low smooth hills. About 8 or 10 miles farther south, with the covering up of the stratified rocks by later eruptives, a corresponding change in the topography takes place. The single main ridge divides into a number of irregular parallel ridges and the low smooth hills change to higher ones which, though sometimes rounded, are often sharp or conical. The tops of these hills often join to form a general mesa. This type of topography extends to the extreme southern end of the range.

SEDIMENTARY ROCKS.

CARBONIFEROUS.

In the northern end of the range limestones and conglomerates associated with thin seams of impure coal have been reported.[a] These

[a] Mon. U. S. Geol. Survey Vol. XX, p. 96.

limestones contain numerous species of Carboniferous fossils. The writer also collected Upper Carboniferous fossils from the vicinity of the road which crosses the Pancake Mountains between Eureka and Hamilton. One locality afforded the following species, which were determined by Dr. Girty:

Fusulina cylindrica.
Fistulipora ? sp.
Derbya sp.
Chonetes verneuilianus.
Rhipidomella pecosi.
Productus sp.
Productus nebraskensis ?
Marginifera muricata ?
Seminula subtilita ?

Another locality, about 2 miles southeast of the first, yielded *Chætetes milleporaceus*, *Spirifer rockymontanus*, *Phillipsia sp.*

These fossils were in shaly gray limestone, which was overlain by more massive limestone, interstratified with occasional belts of conglomerate containing pebbles of quartzite and chert.

DEVONIAN.

South of the road mentioned come in the sandy and limy shales of the Devonian White Pine formation.[a] This shale is associated with beds of brown sandstone which contains plant remains.

TERTIARY.

On the west side of Hastings Pass, in the Humboldt Range, near the northern end of White Pine Valley, are sediments to which was given the name of the Humboldt Pliocene, and which were described and mapped by the Fortieth Parallel Survey. These beds were examined by the writer and were found to consist largely of limestone fragments derived from adjacent Silurian rocks. They abut against the mass of the Humboldt Range in such a manner as to show that this range formed their shore line and that they were deposits formed when the valley had practically its present shape.

In other parts of the valley the Pliocene deposits are generally covered with Pleistocene accumulations, and are therefore not discernible. Along the Pancake Range, however, on the east side of the extreme southern end of Little Smoky Valley, stratified deposits similar to those on the flanks of the Humboldt Range were found, forming a fringe around the mountains.

At Twin Springs the canyon which has been worn transversely across the mountains exposes a section of Tertiary stratified rocks, lying between the Tertiary volcanics. The section shows rhyolite at the base. Above this comes several hundred feet of horizontally bedded

[a] Mon. U. S. Geol Survey Vol XX, Atlas sheet 4.

water-laid semicompacted sandstones, apparently derived from the rhyolite. At the top of this stratified series the white sands change to stratified tuffs and gravels, brown in color and evidently derived from basic lava such as immediately overlies them. This lava is a solid dark-colored basalt, which forms the uppermost member of the series.

PLEISTOCENE LAKE DEPOSITION.

At several points the marks of a comparatively recent body of water, occupying a large part of Big Smoky and White Pine valleys, were observed. On the east side of the Diamond Range, about 10 miles north of Pinto Creek, distinct terraces were observed in the detritus at the base of the mountains. These terraces are several in number and are 50 or 60 feet above the valley floor. Also about 15 miles south of Fish Creek a regular bench composed of lava débris was noted on both sides of the valley, about 15 feet above the smooth mud deposits of the valley bottom. Farther north, at a point on the Pancake Range just south of the road between Eureka and Hamilton, at the mouth of a gap in the hills, a definite beach bar was noticed, such as forms along gently sloping shores at the mouths of inlets.

There was therefore probably a Pleistocene body of water which spread over the greater part of Little Smoky and White Pine valleys. The shore marks above mentioned indicate that this lake was shallow. The final remains of the Pleistocene lake may be considered as still existing in the numerous marshy ponds which are scattered through the White Pine Valley north of the Pancake Range.

GULCH DUMPS OR ALLUVIAL FANS.

Along the line of junction of the mountains with the valleys, and occasionally forming the low foothills, are sometimes observed accumulations of detritus which rise above the level valley floor, and which have such relation to the gulches of the mountains above that it is plain their materials have been derived from their erosion; and in some cases it seems that the amount of material in these dumps is a very large portion of that which has been removed in the excavation of the gulches. Where this material is exposed at the surface, it is found to be angular and bearing other marks of having been brought down by torrents.

These accumulations are certainly, in part at least, Pleistocene, and are being added to at present. However, they antedate largely the Pleistocene water body above described. They are therefore Pliocene-Pleistocene, and are largely contemporaneous with the water-laid deposits which occur at lower altitudes.

IGNEOUS ROCKS.

At the northern end of the Pancake Range a body of rhyolite forms the western half of the mountains and extends as far south as the

road between Eureka and Hamilton. A short distance south of this road andesite comes in in considerable patches.[a] This andesite was observed by the writer at intervals for a distance of 10 or 15 miles south of here. It is here generally mixed up with small areas of rhyolite. Still farther south rhyolite seems to form the greater part of the range (Pl. V, *B*). In the neighborhood of Twin Springs, as mentioned above, the rhyolite occurs at the base of the section and basalt at the top.

STRUCTURE.

FOLDING.

The area of White Pine Devonian rocks, above described, forms a shallow syncline which apparently gives place to a gentle anticline farther north, and there exposes the Carboniferous limestones. It is possible, however, that it is a fault which brings up these limestones. The syncline has a general northwest strike and is plainly continuous with the faulted syncline of the Eureka district, just across the valley, which has Newark Mountain on its eastern limb and the Alhambra Hills on its western. This syncline may be traced across the Pancake Mountains and across the intervening low hills to the White Pine Range, its strike being at an angle to the general trend of the major ridges, although the minor ridges conform to it.

FAULTING.

The Upper Carboniferous limestones on the road across the range, between Eureka and Hamilton, have perhaps been brought to their

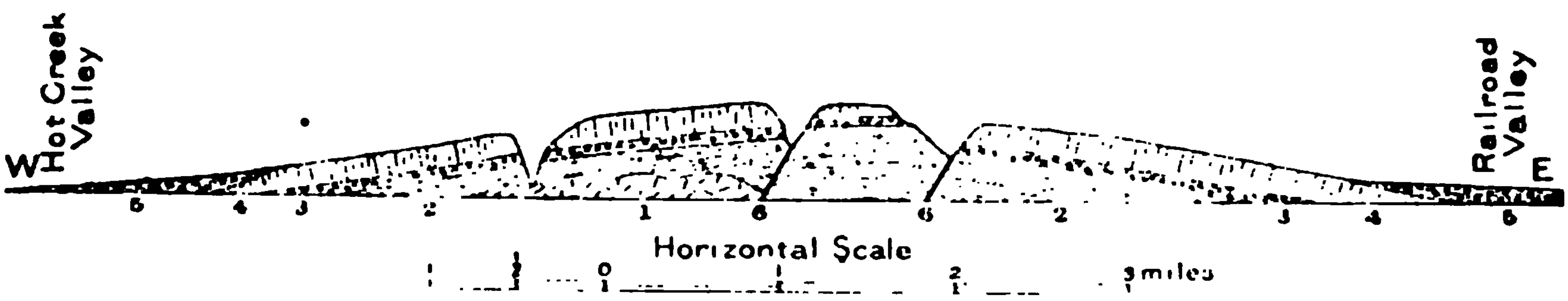

FIG. 6.—Generalized sketch cross section of Pancake Range at north side of pass at Twin Springs.

1. Rhyolite, 200 feet.
2. Rhyolite sandstone, 600 feet.
3. Basaltic tuffs and gravels, 100 feet.
4. Olivine-basalt, 200 feet.
5. Valley wash (Pleistocene).
6. Faults.

present position by an east-west fault, transverse to the trend of the range, for their relation to the Devonian rocks just south of here can not be readily explained by the folding.

The accompanying section (fig. 6) shows the structure of the Pancake Mountains at Twin Springs. There has been practically no folding here, except where the beds have been locally crumpled by overriding sheets of lava. A series of faults was observed, some of which have a throw of several hundred feet. The fault lines are accompanied by gullies, but not by fault scarps.

[a] See Mon. U. S. Geol. Survey Vol. XX, Atlas sheet 4.

COAL.

In the northern end of the Pancake Range the Carboniferous rocks carry thin seams of impure coal, which have been in vain explored for marketable material.[a]

DIAMOND RANGE.

The Diamond Range may be somewhat arbitrarily defined as beginning at Railroad Canyon on the north, and extending southward through the Eureka Mountains to Fish Creek. South of Fish Creek comparatively low mountains occur. No decided break separates these from the Eureka Mountains, but they are more closely associated with the Hot Creek Range, and will be described in the latter connection.

TOPOGRAPHY.

The main part of the Diamond Range, from its northern end to the vicinity of Eureka, consists of a single narrow, somewhat regular ridge, whose divide is in the center. This is sharply cut up on both sides, so as to present a succession of well-defined peaks, with deep drainage channels.

In the neighborhood of Eureka this simple topographic structure changes to a more complicated one, which is the expression of a geologic structure more complicated than that to the north. The mountains in the vicinity of Eureka are considerably folded, and are traversed by numerous faults, which run in several directions. The result of the erosion of this structurally complicated region is that there have arisen many separate mountain ridges, and the total width of the range has increased.

South of the Eureka Mountains the range is composed of a single narrow ridge of stratified rocks, which seem to resume the comparatively simple structure of the northern portion. Just south of here the sedimentaries are buried under thick sheets of lava.

SEDIMENTARY ROCKS.

At the nothern end of the Diamond Range, at Railroad Canyon, the rocks have been described by Mr. Hague[b] as light cream-colored limestones dipping to the north under sheets of basalt. These limestones are mapped by the Fortieth Parallel geologists[c] as the Lower Coal Measures.

The writer traveled along the easterly face of the Diamond Range, from a point just west of Hastings Pass, in the Humboldt Range, to the southern termination. At the northern end of the traverse a sec-

[a] Mon. U. S. Geol. Survey Vol. XX, p. 95.
[b] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 549.
[c] Idem, Atlas, map 4, west half.

tion of strata is visible, which, in default of opportunity for examination, was provisionally supposed to have the Devonian White Pine shale of Eureka at the base, with the Carboniferous Diamond Peak quartzite above.

The thickness of the exposures of these two formations was roughly estimated at from 2,000 to 2,500 feet. Above this section were observed comparatively massive limestones which were taken to be the Lower Coal Measures limestones, and of these an estimated thickness of 4,000 feet was observed. Above these again are heavy brown-weathering massive rocks forming the precipitous crest of the range for a long distance. These were thought to belong to the Weber formation. About 1,500 feet of this was visible, the top not being seen. Mr. Hague[a] notes that at Chokup Pass, which is within the above section, limestones occur in which no fossils were found. "In the limestone occurs a belt of coarse, although compact, brownish-yellow sandstone, not unlike the sandstone body at White Pine, which lies at the base of the Coal Measures limestone. It measures nearly 300 feet in thickness." This is, perhaps, the Diamond Peak quartzite, as it was afterwards called by the geologists who studied the Eureka district.

South of Chokup Pass the same formations occur. In the eastern foothills the Diamond Peak quartzite outcrops, brown, iron stained, friable, and calcareous, resembling exactly the same formation as exposed in the Egan Range, in the canyon west of Ely. The quartzite becomes at times a conglomerate, containing pebbles of chert and limestone. It is possible that this conglomerate indicates an erosion interval between the Carboniferous and the underlying Devonian.

A few miles farther south, the strike of the Diamond Peak quartzite having carried it temporarily under the valley detritus, the eastern foothills are composed of the overlying dark-blue limestone with chert nodules. This limestone carries the following abundant fauna, determined as Upper Carboniferous by Dr. Girty:

Fistulipora ? sp.
Rhombopora lepidodendroides.
Archæocidaris sp.
Productus prattenianus.
Productus semireticulatus.
Productus nebraskensis.
Productus nevadensis ?.
Spirifer boonensis.
Seminula subtilita.
Fish scale.

Still farther south a change in the structure brings in the Diamond Peak quartzite again, together with the underlying Devonian rocks, and the strata rise rapidly to the top of the range.

In Chihuahua Canyon, which lies to the east of Diamond Peak,

[a] U. S. Geol. Expl. Fortieth Par., Atlas, map 4, west half.

slightly fetid limestone was found, and at a point about 1,000 feet above the bottom of the series exposed were Devonian fossils, as determined by Dr. Girty.

Amphipora ? sp.
Spirifer engelmanni.
Spirifer, indeterminable.
Spirifer maia (small variety) ?.
Atrypa missouriensis.

This is part of the Nevada limestone, for the Devonian White Pine shales come in about 500 feet above.

South of here the geology has been thoroughly worked out during the survey of the Eureka mining district, which survey embraces the region from Diamond Peak on the north to White Cloud Peak on the south.

Within this area is found exposed the best Paleozoic section yet studied west of the Rocky Mountains, comprising strata from the Prospect Mountain Cambrian quartzite, through the Cambrian, Silurian, Devonian, and Carboniferous.[a]

South of the Eureka mining district proper, the single ridge into which the mountains contract is shown in the geologic map of the Eureka district[b] to be composed of the Silurian Pogonip limestone. This limestone extends farther south till covered up by volcanic flows.

IGNEOUS ROCKS.

At the northern termination of the Diamond Range the stratified rocks are overlain by flows of basalt.[c] Between this point and the region around Eureka no igneous rocks were observed. The Eureka district, however, has been the seat of volcanic activity. Among the volcanic rocks, hornblende-andesite, dacite, rhyolite, pyroxene-andesite, and basalt have been described by Mr. Iddings.[d] Granite-porphyry is also found as a dike rock.

The volcanic rock which occurs at the southern termination of the range has been determined by the writer, a few miles farther south, to be rhyolite.

STRUCTURE.

North of the Eureka district the stratified rocks of the Diamond Range are bent into a series of gentle folds which in general strike nearly with the trend of the range. In the region between Chokup Pass and Railroad Pass these folds seem to consist of an anticline on the east side, with its eastern limb almost buried by the detritus of the valley, followed by a shallow broad syncline to the west, and this

[a] Arnold Hague, Geology of the Eureka district, Nevada: Mon. U. S. Geol. Survey Vol. XX; C. D. Walcott, Paleontology of the Eureka district: Mon. U. S. Geol. Survey Vol. VIII.
[b] Mon. U. S. Geol. Survey Vol. XX, Atlas sheet 4.
[c] Arnold Hague, U. S. Geol. Expl. Fortieth Par., Vol. II, p. 549.
[d] Mon. U. S. Geol. Survey Vol. XX, p. 233 et seq.

in turn by an important anticline which seems to form the western edge of the mountains.

At Chokup Pass Mr. Hague[a] notes the general anticlinal structure of the mountains, the summit of the anticline occupying the crest of the pass. This is the same anticline as has just been noted as forming the western face of the mountains to the north of the pass, the slight divergence of the strike of the fold from the trend of the mountain bringing the fold to this place. Farther south the continued divergence brings the axis of this anticline at one point down to the easternmost foothills. As a consequence of this, the syncline and anticline which lie to the east are covered by valley detritus. Farther south still, as one approaches the vicinity of Diamond Peak, the trend of the folds changes slightly and again brings the crest of the easternmost anticline to the summit of the range.

South of Diamond Peak the country in the neighborhood of Eureka is a region of special dynamic disturbance, and is folded and faulted to a remarkable degree. Except in this district, however, no faults have been observed in the range.

RELATION OF STRUCTURE TO TOPOGRAPHY.

North of the Eureka district the structure has been so far influential that the trend of the range corresponds nearly to the general strike.

In the Eureka district the complicated topography is dependent upon the increased complications in the geology, but the forms appear to be directly due to differential erosion. Most of the faults here are oblique to the general trend of the range. Along these faults valleys or canyons are sometimes found, and sometimes moderate scarps; but that these latter are due to differential erosion is shown by the fact that it is sometimes the downthrown side of the fault that appears as a scarp and sometimes the upthrown, depending upon the nature of the beds.

ORES.

The whole district around Eureka has been the site of abundant ore deposition, a phenomenon plainly connected with the dynamic disturbances which have brought about the complicated folding and faulting (and indirectly the topography) and with the volcanic outbursts. The ore deposits of Eureka have already been thoroughly studied.[b] Outside of this region the range is not remarkably ore bearing.

HOT CREEK RANGE.

The Hot Creek Range is separated at its south end by a narrow pass from the Kawich Range, which otherwise is continuous with it.

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[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 549.

[b] J. D. Curtis, *Silver lead deposits of Eureka*: Mon. U. S. Geol. Survey Vol. VII; Arnold Hague, *Geology of the Eureka district*: Mon. U. S. Geol. Survey Vol. XX.

From here it runs north 70 miles and disappears in a valley a few miles south of the latitude of Eureka. In the same line, farther north, occurs the Piñon Range. The northern continuation of the Hot Creek Valley divides the mountains into an east and a west half. The western half is the continuation of the Hot Creek Range proper, while the eastern one runs north and joins the Eureka Mountains.

SEDIMENTARY ROCKS.

SILURIAN.

At the eastern end of the canyon, at Hot Creek, the following section was observed, beginning with the bottom:

Section at Hot Creek.

	Feet.
1. Thin-bedded, dark-blue frosty-lustered limestone, calcite-veined, with imperfect fossil remains	400
2. Massive white quartzite	400
3. Thin-bedded dark-blue limestone	200
4. Shales mixed with thin-bedded limestone	1,000
5. Massive light-gray coarsely crystalline limestone, constituting the top of the mountain	500

Three miles west of this locality, at the ranch near Hot Springs, there comes in, below bed No. 1, more massive siliceous light-gray, coarsely crystalline or aphanitic limestone about 600 feet in thickness. This makes about 1,000 feet of limestone in all below the quartzite.

From the first-named locality, at a point about 200 feet below the quartzite, Ordovician fossils were obtained. The following were determined by Professor Ulrich:

Amphion (sp. near A. salteri Billings).
Illænus (sp. near I. americanus, consimilis, and crassicauda).
Bathyurus sp. undet.
Leperditia bivia White.
Leperditia n. sp.
Aparchites sp. undet.
Primitia (sp. near P. celata Ulr.).
Primitia (? Eurychilina) n. sp.
Eurychilina (near E. subæquata) Ulr.
Schmidtella n. sp.
Thlipsura? n. sp.
Modiolopsis occidens, Walcott.
Maclurea.
Tetranota (n. sp. near T. obsoleta Ulr.).
Lophospira (cfr. medialis Ulr.).
Pleurotomaria ? lonensis Walcott.
Triptoceras sp. undet.
Orthis n. sp. (near O. holstoni Safford).
Dalmanella pogonipensis, H. and W.
Batostoma, sp. undet.

It is, then, plain that the quartzite is the Eureka quartzite of the Eureka section, while the limestone below corresponds to the Pogonip formation and that above to the Lone Mountain. We have here a section of about 3,100 feet of Silurian rocks, comprising 1,000 feet of the Pogonip, 400 feet of the Eureka, and 1,700 feet of the Lone Mountain.

A few miles south of the above locality, in the next canyon to the south of Hot Creek, there were collected from the limestones above the quartzite the following Upper Silurian fossils (Niagara ?), as determined by Professor Ulrich:

Halysites catenulatus, large variety.
Halysites catenulatus, small variety.
Favosites (ramose species).
Syringopora sp. undet.
Amplexus sp. undet.
Cyathophyllum sp. undet.
Zaphrentis ? sp. undet.
Rhynchonella sp. undet.

At Tybo, about 15 miles south of Hot Creek, and also on the east side of the range, the rocks appear to be mainly massive dark-blue limestones with a general westerly dip. This locality was not visited, but a single fossil obtained from these limestones was regarded by Dr. Girty as probably Ordovician, *Maclurea annulata ?*

From Tybo to the south end of the range, just west of Twin Springs, in the Pancake Range, the east half of the mountains is entirely composed of similar limestones. At the extreme south end the limestones are overlapped by the rhyolites of the Kawich Range, which have altered the sedimentary rocks. No fossils were found at this point, but a specimen of the limestone was seen under the microscope to be made up of tiny indeterminable organic remains.

TERTIARY.

On the eastern side of the range, extending from Hot Creek a number of miles in both directions, are gray hills composed of partly consolidated coarse gravel and grit. This material often overlies rhyolite, from which it is partly derived, and it rests against the steep eroded base of the limestone mountains. The material is evidently waterlaid. The same formation stretches southward and is visible near Tybo as a strip of yellow dissected hills. At the pass between the Hot Creek Range and the Kawich Range are large amounts of horizontally stratified white waterlaid deposits composed of rhyolitic fragments.[a]

This formation is evidently the same as described in the neighborhood of Twin Springs, in the Pancake Range, a few miles to the east.

[a] This formation is chiefly included under the color for volcanic rocks on the map. The narrow strip near Tybo is not represented.

IGNEOUS ROCKS.

LAVAS.

The whole north end of the Hot Creek Range, beginning with a point a few miles north of Hot Creek, is, so far as known, composed entirely of volcanic rocks, including both rhyolite and basalt. There has been much erosion since the outpouring, resulting in the carving of considerable valleys and the formation of large gulch dumps (alluvial fans) at their mouths, exactly as in the case of the stratified rocks. In places, also, erosion has stripped away the upper layers of lava and ash and has exposed symmetrical volcanic cones, which have been preserved by this protecting covering. Pl. V, *B*, is a photograph of such a cone. The number of these small cones and the abundance of ash, together with the thinness of the lava sheet, show that the volcanic rock in this region came from many separate explosive vents.

In the neighborhood of Hot Creek, as before stated, the eastern half of the range contains a considerable area of Silurian rocks. However, rhyolite is found at the extreme eastern base, and the whole western half of the mountain at this point is composed of several thousand feet of the same rock. From here to the southern end of the range the western part is of volcanic, while the eastern half is mostly stratified. At the southern end the rhyolite mantles around to the east to join the lava of the Kawich Range.

STRUCTURE.

In Hot Creek Canyon the Silurian rocks form an anticlinal fold, broken by two or three normal easterly dipping faults. The first of these faults occurs at the eastern end of the canyon, and by it the strata, including the Eureka quartzite, are down-faulted to the east 200 or 300 feet. This fault was also noted in the first canyon south of Hot Creek. Three miles farther west occurs a second parallel fault. This fault has a vertical separation of about 1,000 feet, as marked by the Eureka quartzite, upthrown on the west. (See fig. 7.)

From Hot Creek to the southern end of the range the structure was not carefully examined, but for nearly the whole way the limestones can be seen to dip in general westerly at an angle of from 15° to 20°. It is probable that this dip represents the westerly limb of the anticlinal fold exposed in Hot Creek Canyon.

ORES.

Along Hot Creek Canyon are some vertical zones in which rich pockets of ore are said to have been found. These zones are apparently ancient channels of the hot springs, which still exist. South of this point the rocks are more or less mineralized all the way to Tybo, where there are some important ore deposits.

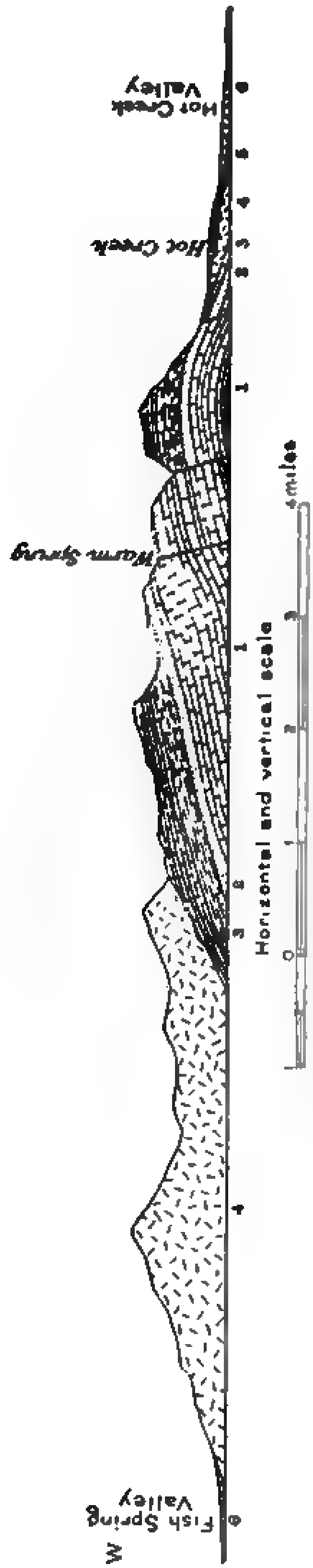

FIG. 7.—Generalized sketch section across Hot Creek Range at Hot Creek.

1. Pogonip (Ordovician) thin-bedded, dark-blue limestone underlain by more massive limestone.
2. Eureka quartzite.
3. Upper Silurian (corresponds to Lone Mountain formation of Eureka), shales and thin-bedded limestone overlain by more massive limestone.
4. Massive rhyolite.
5. Stratified older gravels (Pliocene?).
6. Valley wash (Pleistocene).

PIÑON RANGE.

The Piñon Range is mentioned in this report only because its southern end, which extends beyond the southern limit of the Fortieth Parallel maps, is included in the accompanying map. The writer did not visit this range, and the following slight summary is taken chiefly from the work of the Fortieth Parallel geologists.

TOPOGRAPHY.

The range consists of a single main ridge, which is conspicuous north of the fortieth parallel and lies next west of the Humboldt Range. Farther south the Diamond Range comes in between the two. Near this point the Piñon Range becomes lower, and its trend changes from south to southeasterly, so that it swings around and joins the Diamond Range near Eureka.

SEDIMENTARY ROCKS.

In the neighborhood of Pinto Peak there is exposed a thickness of about 14,000 feet of sedimentary rocks,[a] comprising a section from the Cambrian up into the Carboniferous. South of this the range is almost entirely composed of Devonian rocks. These Devonian rocks are continuous southward to the junction with the Eureka Mountains.[b]

IGNEOUS ROCKS.

VOLCANIC ROCKS.

Throughout most of the extent of the range various volcanic rocks are found, both at the east and the west bases.

[a] Arnold Hague, U. S. Geol. Expl. Fortieth Par., Vol. II, p. 554.
[b] Arnold Hague, Geology of the Eureka district. Mon. U. S. Geol. Survey Vol. XX, p. 200.

STRUCTURE.

As stated by Mr. Hague,[a] the range consists of open anticlinal and synclinal folds. South of Pinto Peak the structure is anticlinal, the axis of the fold striking diagonally across the range S. 25° E., while the general trend of the range at this point is west of south. It is likely that the main anticlinal fold of the Diamond Range is the direct continuation of this anticline. Farther south, along the Piñon Range, this anticline gives way to an adjacent syncline, and farther south again the eastern limb of this syncline is cut off by the valley, so that only the western or easterly dipping limb remains. This portion of the range, therefore, has the aspect of being monoclinal.

A section made by Mr. Walcott,[b] at Ravens Nest, just north of Pinto Peak, shows the structure as a faulted anticline.

MONITOR RANGE.

The Monitor Range is a belt of mountains about 70 miles long, lying next west of the Hot Creek Range. It has its northern end just south of the area shown on the Fortieth Parallel maps. The northern part of the range, up to within a few miles of Altoona Pass, has the aspect of a great west-sloping table which ends in a scarp on the west, facing the valley. At Altoona Pass the range is narrower and has a very sharp summit, with a steep descent on both sides. Farther south the range grows lower and is broken by frequent gaps, till it passes into low volcanic hills and dies out in the Ralston Desert.

Gilbert[c] has observed a single spur of metamorphic rock on the west side of the range at its southern end. Otherwise the whole southern part of the range, as observed by Mr. Gilbert and the writer, is volcanic. At Altoona Pass the lava is a siliceous rhyolite like that of the Hot Creek Range.

It is probable that this range has been formed by a series of volcanoes along a north-south line. The topography of the southern part of the range (like that in the southern parts of the Toquima and Pancake ranges) is extremely irregular, consisting in part of interrupted mesas and ancient volcanic cones defaced by erosion. It is plain from this topography that the lavas have escaped from many different vents and have flowed together. Erosion of the lava has gone on to a considerable extent, indicating the lapse of some time since the cessation of volcanic activity.

WAHWEAH RANGE.

The name Wahweah Range is applied to an irregular cluster of hills west of the southern end of the Piñon Range and just within the

[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 551.
[b] Mon. U. S. Geol. Survey Vol. XX, p. 201.
[c] U. S. Geog. Surveys W. One Hundredth Mer., Vol. III, p. 121.

northern limits of the accompanying map. It was not visited by the writer, and the following brief characterization is taken from the reports of the Fortieth Parallel Survey:

The range is about 30 miles long and at its northern end consists mainly of granite, together with a heavy body of quartzite, which was referred to the Ogden Devonian on lithologic grounds, there being no fossils. The sedimentary rocks are here flanked by flows of volcanics, which farther south mantle over the stratified rocks and constitute most of the surface, exposing the underlying Paleozoic only in patches.[a]

TOQUIMA RANGE.

The Toquima Range is situated next west from the Monitor Range. It has a trend a little east of north and a total length of about 80 miles. At its north end it passes into the level desert east of Austin, and its south end is situated southwest of Belmont, on the borders of Ralston Valley. The San Antonio Mountains are an irregular clump, south of the Toquima Range, and are separated from this range by a gap only a few miles wide. They are surrounded on all sides by detritus-covered plains.

TOPOGRAPHY.

The Toquima Range has comparatively great relief. In general it consists of a single ridge of moderate breadth. At its southern end, near the town of Belmont, this splits in two, the main ridge trending a little west of south toward the San Antonio Mountains, while a minor one diverges and runs in a southeasterly direction into the Monitor Range. Between the two ridges is a low valley, filled with Pleistocene detritus.

The range is essentially volcanic, but in places is exposed a core of Paleozoic rocks beneath, indicating that here, as in the Hot Creek Range, the Antelope Mountains, and others, there existed a distinct range of Paleozoic rocks before the lava effusion, which has now almost completely masked the stratified rocks and given the range the aspect of being primarily volcanic.

SEDIMENTARY ROCKS.

The range was crossed by the writer only at one point. His route lay from the town of Belmont, around the southern end of the range, along the road to Cloverdale. Along this route no stratified rocks could be seen in the range. North of Belmont all is apparently volcanic. This impression has been confirmed by reconnaissance notes made by Messrs. Gilbert[b] and Emmons.[c] Mr. Emmons suggests that

[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 566.

[b] U. S. Geol. Surv. W. One Hundredth Mer., Vol. III, p. 121.

[c] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 333.

the core of the range some distance north of Belmont may be composed of stratified rocks, but the first point where they have been observed is just east of Belmont, where occurs a series of black limy slates and gray finely crystalline limestone, banded black and white, and often siliceous. The formation is preeminently a slaty one and has often the aspect of a schist. This aspect is due to metamorphism, occasioned by certain siliceous dikes of the granitic family. One great dike is half a mile wide and runs in a north-south direction. Near its junction the shaly limestones become transformed into jasperoid, and in places by the development of mica the rock passes into mica-schist. Some of the jasperoid is also schistose, and contains small bunches of red and yellow metallic oxides, which give it the aspect of a knotted schist.

The stratified rocks here are tilted at high angles. Where observed by the writer they were mostly vertical, but Mr. Emmons found a general easterly dip.

In the slates Mr. Gilbert[a] found graptolites, which referred the rocks to the Silurian age. According to Mr. Walcott,[b] the rocks probably correspond to a part of the upper Pogonip formation of Eureka. Mr. Gilbert[c] estimates the apparent thickness of the stratified series at Belmont at 4,000 or 5,000 feet.

On the road leading from Belmont southwest toward Cloverdale the same series of strata is found at the eastern base of the main ridge. The chief rock is compact limy black slate, often metamorphic and schistose, corresponding closely with the rocks just east of Belmont. The metamorphism is evidently, as in the former case, connected with intrusive masses of granite and rhyolite. By these the slate is sometimes transformed into an unsheared jasperoid or to a quartz-schist (the latter often containing actinolite and staurolite) and sometimes into highly crystalline mica-schist. A mile south of the most northern outcrop found the shales are overlain by about 200 feet of massive white quartzite, which is probably the Eureka formation. The quartzites and underlying beds are exposed south of here for some distance till they disappear under Pleistocene detritus on one side and volcanic rocks on the other. Farther southwest, however, at the spring, is found another small patch of the schistose slates capped by the quartzite. This patch is surrounded on all sides by rhyolites, and is chiefly altered into jasperoid seamed with iron.

Looking eastward from the eastern base of the main ridge a portion of the minor ridge which runs southeasterly from Belmont is seen to be composed of stratified rocks similar to those just described. Apparently the schists and the overlying white quartzite can be recognized.

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[a] U. S. Geol. Surv W One Hundredth Mer., Vol. III, p 180.
[b] Mon. U. S. Geol. Survey Vol. VIII, p. 2.
[c] Op. cit., p. 36.

IGNEOUS ROCKS.

LAVAS.

The whole northern part of the Toquima Range appears to be covered up by great flows of rhyolite. Just east of Belmont the foothills bordering the area of stratified rocks are composed of rhyolite running out to the north toward the main mass. Rhyolite is also found in large quantities southwest of Belmont. This area stretches north and, growing broader, joins the great mass which covers the northern part of the range. To the south also it appears to stretch across the gap to the San Antonio Mountains. Similarly, the rocks of the minor ridge which runs southeast from Belmont are mainly rhyolites, forming a continuous body with the rhyolites of the Monitor Range.

DIKE ROCKS.

Near Belmont there is a considerable development of coarse-grained granitic rocks. In several cases these are found to be intrusive into the stratified rocks. A mile south of Belmont is an exposure of coarse granite-porphyry with sparse biotite and numerous large orthoclase phenocrysts from 2 to 4 inches long. This may be continuous with the great dike before noted as running north and south just east of Belmont and having a width of half a mile.

The rocks of this dike, however, are different, being finer grained and in general more siliceous. They consist chiefly of quartz and feldspar. In some places the rock becomes mostly quartz; in others mainly feldspar. Quartz veins are abundant, irregular, and segregational, and evidently are the results of crystallization contemporaneous in a general way with the crystallization of the rest of the rock. Biotite is often sparsely present, and in some places the rock contains considerable muscovite and even passes into muscovitic quartz veins. Thin sections of the rock examined show in one case a fine-grained biotite-quartz-monzonite; in another case siliceous muscovite-biotite-granite, peculiar in having certain areas entirely of quartz. This rock is evidently closely related with another which is essentially composed of quartz and muscovite, with a little albite. This is a variation of the muscovite-biotite-granite, in which muscovite has largely taken the place of feldspar. The distinction between this type and the micaceous quartz veins which occu[illegible]lose connection with it, is not sharp[a].

STRUCTURE.

The Silurian shales which occur just east of Belmont have a strike of N. 35° W., and change from vertical to a generally easterly dip. Southwest of Belmont, on the eastern side of the main ridge, the same

[a] J. E. Spurr, Quartz-muscovite rock from Belmont, Nev.: Am. Jour. Sci., 4th series, Vol. X, 1900, p. 351.

rocks have a general north-south strike and a westerly dip of 20°. The two locations, therefore, may be on the two limbs of an anticlinal fold. The further structure of the stratified rocks is concealed beneath the lava flows.

ORES.

In the vicinity of Belmont there has been considerable ore deposition, which in the time of Nevada's prosperity made the region one of considerable wealth. At present the mining industry is perfectly dormant. During the period of activity the region was described by Mr. Emmons.[a] According to him the ores occur generally in white quartz veins, often several feet in width, and consist principally of stetefeldtite (an argentiferous ore of antimony) with which is combined lead, silver, copper, and iron. The metallic minerals are scattered through the quartz in bunches or disseminated particles—rarely in banded form. The veins are found cutting the Silurian shales and limestones, and frequently are close to the intrusive granitic dikes.

It appears to the writer that there is a genetic connection between the intrusive rocks and the metalliferous quartz veins of this district.[b]

TOYABE RANGE.

The Toyabe Range lies next west of the Toquima and extends southward about the same distance. To the north, however, it has a greater length, running along the western border of the desert into which the Toquima Range merges at its northern end. Thus the entire length of the Toyabe Range is about 100 miles. It has a uniform north-northeast trend.

That portion of the Toyabe Range which lies north of Austin has been included in the general maps of the Fortieth Parallel Survey. From Austin southward nearly to the southern end of the range, the mountains have been made the subject of a special study by Mr. Emmons.[c] The writer observed the range at its extreme southern end, and also its western base, along the valley which separates it from the closely adjacent Reese River Range.

TOPOGRAPHY.

The topography of the Toyabe Range is marked by features of considerable contrast, the mountains being sharp and high and the intervening canyons deeply cut. Throughout most of its course the range consists of a single ridge in its central portion. The southern ends of this range and of the Reese River Range converge until they almost unite.

The southern part of the range is essentially volcanic; while the rest is composed chiefly of granite and Paleozoic strata. The erosion

[a] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 383.

[b] J. E. Spurr, Am. Jour. Sci., 4th series, Vol. X, 1900, p. 355.

[c] Op. cit., p. 320; Atlas, Pl. XIII.

of the lavas appears to have been quite as profound as that of the stratified rocks, showing that a considerable period has elapsed since the effusion of volcanic material.

In the valley which separates the southern end of the Toyabe Range from the corresponding portion of the Reese River Range there is a high divide, separating the north-flowing drainage of Reese River from that which flows south into the desert plain at Cloverdale. The south-flowing drainage runs in a canyon cut into the bottom of the valley, with rhyolite walls which go up at angles of from 45° to 65° to heights of 700 or 800 feet. At its bottom is a level floor covered with wash and sagebrush, and in the center of this floor is an arroyo 5 or 6 feet deep. At Cloverdale this bottom is one-quarter of a mile across, while 7 or 8 miles up it is barely 30 yards. The stream which flows in this canyon is derived from a spring. This case is like one described in the Snake Range region.

Another noteworthy feature of the erosion of this range, according to Mr. Emmons, is the occurrence of basins at the heads of some of the canyons, which basins, he infers, were formerly occupied by glaciers. At the mouth of one of the canyons Mr. Emmons[a] found glacial striæ, which strengthened his belief. On most of the Great Basin ranges, as is well known, there are no marks of glaciation.

SEDIMENTARY ROCKS.

CAMBRIAN.

All the stratified Paleozoic strata of the Toyabe Range were mapped by the Fortieth Parallel geologists as Carboniferous, since Carboniferous fossils were the only ones found in the series. These occurred in limestones. Beneath the limestones was a thick series of slates, which were regarded as the same as those in the Toquima Range near Belmont. The subsequent finding by Mr. Gilbert of fossils in the Belmont slates determined them as Silurian. Beneath these slates, in the Toyabe Range, Mr. Emmons has described a series of compact white quartzites with some thin beds of white granular limestone, the series being several thousand feet thick. The quartzites underlie the slate series in apparent conformity, and outcrop in places along the eastern face of the south half of the range.

Farther north, beyond Austin, the high mountain called the Dome has been described by Mr. Hague[b] as consisting of nearly white quartzite beds, which seem to be bent into a broad anticlinal fold. These are overlain by beds of siliceous and argillaceous slates, and these by compact gray limestones. This is evidently the same series as described by Mr. Emmons. The thickness of the quartzites is not estimated, but must be great.

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[a] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 328.
[b] Idem, Vol. II, p. 630.

No fossils were found in these quartzites, but in the Eureka section no such quartzite exist except that of the basal Cambrian; and the position of this series in the Toyabe Range ~~above~~ below probable Silurian slates strengthens the belief that it also is Cambrian.

SILURIAN.

As before noted, Mr. Emmons has described, overlying the heavy quartzites, an estimated thickness of 7,000 feet of limestone shales, with siliceous clay slates, locally metamorphosed into schistose rocks. Mr. Emmons regarded these slates as the same as at Belmont. In these latter rocks Silurian fossils have since been found. In the Eureka section the thickness of the Silurian is estimated at 5,000 feet.

This slate series occupies the central portion of the range, the general structure being anticlinal.

DEVONIAN.

Whether or not the Devonian exists in this range is not certain. The presence of Carboniferous and probable Silurian makes it seem very possible that the Devonian also comes in, although it has not been recognized.

CARBONIFEROUS.

Overlying the slate series which has just been referred to the Silurian, Mr. Emmons[a] has described a compact dark-blue limestone which lies conformably upon the slates and is exposed on both flanks of the range on the two sides of the general anticlinal fold which is the chief structural feature. In this limestone, Mr. Emmons found *Fusulina cylindrica* and *Syringopora*.

TERTIARY.

Near the northern end of the range Mr. Hague[b] has described, beneath rhyolite, beds of volcanic ash which, although without determinable fossils, he referred to the Miocene. These beds are older than the rhyolite and have been disturbed, since their deposition, by the intrusion of igneous rocks, so that they underlie unconformably supposedly Pliocene strata, which are younger than the rhyolite.

IGNEOUS ROCKS.

A considerable portion of the Toyabe Range is made up of granite and volcanic rocks.

GRANITE.

Mr. Emmons[c] has described five bodies of granite, all intrusive into Paleozoic strata. The rocks vary somewhat in texture and composition, but are generally markedly siliceous, being characterized by a

[a] U. S. Geol. Expl. Fortieth Par., Vol. III, p 323. [b] Idem, Vol. II, p. 630. [c] Op.

large proportion of quartz, an almost entire absence of hornblende, and a small proportion of mica. Associated with the granite are fine-grained dikes.

RHYOLITE.

Volcanic rocks occur at intervals along the flanks of the range, but the most important mass is at the southern end, where for 30 miles it completely conceals the granite and the stratified rocks.

Among the volcanic rocks, rhyolite is the only one that has any very wide distribution, so far as observed. Mr. Emmons notes that rhyolite occurs in exceptionally large masses and is of comparatively uniform coarse texture, having a granitic appearance in the hand specimen. At the southern end of the range the present writer has studied the rhyolites, which are here associated with tuffs. The general type is biotite-hornblende-rhyolite, similar to the lava which forms the southern end of the adjacent Toquima Range.

AUGITE-BASALT.

In the little valley which separates the southern end of the Toyabe Range from the Reese River Range there was found, near the head of the Reese River drainage, a small area of augite-basalt.

RELATIVE AGE OF THE IGNEOUS ROCKS.

As in the Toquima Range, the intrusive granites of the Toyabe Range and the rhyolites show marked consanguinity in composition. Each is characterized by biotite as the chief ferromagnesian mineral.

The augite-basalt is decidedly younger than the rhyolite, since it was poured out in a valley which has been deeply cut into the latter rock.

STRUCTURE.

According to Mr. Emmons[a] the range owes its existence chiefly to a lateral compression, which has thrown the stratified rocks into north-south anticlinal and synclinal folds. In addition to this there has been another pressure, coming from a different direction, which has distorted and dislocated these folds. The main fold of the range is an anticline, which occupies the whole central part of the range. The axis of this fold has an extreme variation from northeast at its northern end to northwest at its southern. South of here, at Ophir Canyon, Mr. Emmons noted a syncline, probably adjacent to the main anticline. This syncline, however, was probably formed by the intrusion of granite. To the north of the central part of the range, in the vicinity of Austin, another synclinal fold appears, which also seems to be connected with a granitic intrusion. Farther north,

[a] U. S. Geol. Expl. Fortieth Par., Vol. III, p. 326.

as stated, the structure of the high mountain called the Dome appeared to Mr. Hague[a] to be anticlinal.

ORES.

Formerly the ores of the Toyabe Range were of great economic importance, but with the decline of the mining industries of Nevada they have been almost forgotten. The principal mining region was in the neighborhood of Austin, but mines were found from here southward all along the range. Mr. Emmons has described many of the deposits, which in nearly every case consist of veins of white quartz carrying metallic sulphides in irregularly disseminated bunches and streaks. In the vicinity of Austin, the oldest mining district in the State, the veins are mostly in granite, and rich ores do not appear to occur in other rocks. In other parts of the range, however, the veins occur in the stratified rocks. Besides quartz as gangue mineral, manganese spar and calc spar were noted, while the metallic sulphides comprise proustite, pyrargyrite, stephanite, polybasite, tetrahedrite, argentiferous galena, zinc blende, copper pyrites, and iron pyrites. In some of the veins the chief silver-bearing mineral is a mixed sulphide of antimony, as is the case in the neighborhood of Belmont. The veins are often faulted.

As in the case with the ores at Belmont, there is probably an intimate connection between the metalliferous quartz veins and the intrusive rocks.

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[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 630.

CHAPTER II.

RANGES OF WEST-CENTRAL NEVADA.

REESE RIVER RANGE.

The Reese River Range lies next west of the Toyabe Range, from which it is separated only by a narrow north-south valley at its southern end. From here it extends in a direction a little east of north about 100 miles into the area of the Fortieth Parallel surveys. Farther north the same general line of elevations is continued in the Shoshone Range.

TOPOGRAPHY.

So far as observed, the Reese River Range is composed entirely of igneous rocks, and the forms produced by erosion have therefore a certain uniformity. The summits show peaks which resemble remnants of ancient volcanic cones, and the valleys which furrow the flanks are deeply cut.

The valley which separates the Reese River Range from the Toyabe Range at its southern end has considerable interest. Its broad rounded form, as contrasted with the sharp incision of the lesser mountain valleys, shows that it has not been produced since the effusion of the lavas, but existed previously; yet the bottom of the valley consists of an unknown thickness of lava, similar to that of the mountains on both sides. Subsequent to the period of effusion, erosion has formed deep gorges in the valley bottom.

Fifteen miles north of the southern end of the Reese River Range there is in the valley a divide which separates the northward-flowing drainage of Reese River from that which runs south. The southward-flowing drainage is in a canyon which is cut below the main valley floor 700 or 800 feet.[a] On the north side of the divide, the descent is sharp into a broad, V-shaped valley cut in the rhyolite. Farther north, where the mountains diverge, the valley suddenly widens, and at the same time the topography of the base of the mountains on both sides changes, a broad, gently sloping plateau taking the place of the irregular hill topography of the higher valley. In the middle of this plateau the valley in which the uppermost drainage of Reese River flows is several miles wide.

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[a] See p. 94.

IGNEOUS ROCKS.

So far as seen, the range is composed mainly of great masses of rhyolite, similar to the lava which makes up the southern end of the Toyabe Range. Along the eastern base of the mountains, at their southern end, are abundant deposits of white volcanic ash. The eruptions which poured out the lava must, therefore, have been of an explosive nature.

In the valley between the Reese River Range and the Toyabe Range, at a point southeast of Ione, a flow of augite-basalt was found. On the opposite side of the range, in the vicinity of Ione, there is a considerable body of the same rock.

On the edge of the desert valley, 1 or 2 miles west from Ione, there is a basic lava which appears, upon microscopic examination, to be biotite-andesite.

The low ridges running south from Cloverdale to the Monte Cristo Mountains are mainly flat volcanic mesas. As seen from the vicinity of Ione, the Reese River Range for 10 or 15 miles north is evidently volcanic, and is probably mainly so up to the junction of the Fortieth Parallel map, where the Shoshone Range is represented as all rhyolite.

AGE OF LAVAS.

The augite-basalt on both sides of the range is plainly younger than the rhyolite, and appears to lie against the flanks of the hills eroded from it.

ELLSWORTH RANGE.

The name Ellsworth Range is here applied to the extreme southern end of a series of rather disconnected ridges which farther north are known as the Desatoya Mountains. This southern end, so named from the decayed mining camp of Ellsworth, is narrow, and consists of a single ridge which reaches a moderately great altitude.

In general the range seems to be composed of an ancient series of volcanics and derived tuffs, with limestones. These are cut by dikes and are capped and often entirely hidden by late volcanic flows.

SEDIMENTARY ROCKS.

The range was crossed by the writer between Ellsworth, on the east side, and Downieville, on the west. On the road some miles west of Ellsworth is a comparatively small outcrop of white granular limestone, consisting of loosely cohering calcite crystals, which give a granular appearance not unlike that of sandstone. This rock is associated with an altered green rock of probable igneous origin, which is cut by siliceous dikes and is frequently mineralized. The only specimen of the green rock examined turned out to be made up of epidote, quartz, and calcite, all probably secondary and resultant

from alteration accompanying the introduction of the metallic sulphides which are frequently found disseminated in the rock.

On the summit of the pass, separated from the locality just mentioned by a sheet of overlying basic lava, there is found, immediately beneath the volcanic rock, a dense sandstone or tuff, which on microscopic examination is found to consist of rounded quartz grains and altered feldspar fragments. This tuff contains occasionally angular fragments of lava and also doubtful plant remains.

From here to the foot of the comparatively steep scarp which occurs along the western face of the range, there is a vertical distance of nearly 2,000 feet. The section shows a single rock series, all probably of igneous origin. The rocks are reddish or greenish, often trap like and nearly always contain abundant angular fragments of lava, giving the appearance of a breccia. Rock having the appearance of red sandstone is common, but when examined under the microscope this is found to consist chiefly of highly altered feldspar fragments, with some calcite and epidote, the whole being stained with iron oxide. It is probable, therefore, that this rock is also a volcanic tuff. More abundant than this apparent red sandstone is a dense, greenish-looking rock, which microscopic examination shows to be probably a hornblende-biotite-syenite-porphyry. Below the chief mass of this igneous rock there is again found a great thickness of feldspathic tuff, which is highly colored in the hand specimen. Under the microscope the tuff is seen to be made up of rounded and broken fragments of feldspar in a kaolinic matrix, the whole colored by iron oxide. Below this again there is found white volcanic tuff, resembling ash, but containing some rounded, apparently waterworn, grains.

The dip of this series of igneous rocks and tuffs seems to be in general to the west, although the folding on a small scale is considerable.

At the base of the abrupt mountain scarp is found a moderately thin-bedded siliceous limestone, without fossils. The general strike is north and south, and the dip 20° to 30° W. This rock is found continuously to the end of the foothills at Downieville, where dark-blue limestone alternates with beds of white and gray granular limestone or marble.

In the whole series exposed in the Ellsworth Range no fossils were found, except in the limestone just east of Downieville, where they were too poorly preserved to warrant collection.

The marble or white granular limestone at Downieville resembles that described on the east side of the mountain, above Ellsworth. In both places there is a north-south strike. The dip in the occurrence near Ellsworth is an easterly one of 4°, while near Downieville it is westerly, averaging 20° or 30°. It may be, therefore, that the two occurrences are on opposite sides of an anticlinal fold. If this is the case, then the thick series of interstratified igneous rocks and

tuffs which constitutes the core of the mountain lies beneath the limestone series. The volcanic series must be at least 2,000 feet thick, the limestone series hardly less.

If we had no other data than the preceding we would hardly be able even to suggest the age of the rocks. We have, however, from the researches of the Fortieth Parallel geologists, in the region not far north, results which may help us in correlating. In this same range near New Pass Peak, about 60 miles northeast, are Triassic strata which Mr. Emmons has described in the following terms[a]:

The lowest exposures show strata of a greenish, somewhat cherty quartzite. Above these, forming the summit of the ridge, is a breccia-like conglomerate, made up of greenish and purple cherty fragments, with a red cement, overlaid by a thickness of about 1,000 feet of quartzite and conglomerate, weathering with a peculiar yellowish-brown earthy surface. On the western slopes, immediately underlying the limestones, is a bed of purple, argillaceous roofing slate. As exposed in Ammonite Canyon, there lies conformably above this a thickness of 1,000 to 1,500 feet of dark grayish-blue, compact, earthy limestones of the Star Peak group, which lithologically can not be distinguished from the Carboniferous limestones. At the contact of the limestones with the quartzites is a band of yellow calcareous shales.

The underlying greenish cherty quartzite and breccia-like conglomerate with red cement, described by Mr. Emmons, recalls the central mass of tuffs and volcanic rocks near Ellsworth, while the overlying dark grayish-blue limestones are similar to those near Downieville. Immediately above the limestones Mr. Emmons found abundant Triassic fossils in a series of shales which were not observed in the Downieville section

The lower of the two series at New Pass Peak has been correlated by Mr. King with the Koipato formation, and the underlying limestone with the Star Peak formation, both formations occurring in the Triassic of West Humboldt Range. Concerning the Koipato in the West Humboldt Mountains, Mr. King writes that at the base it consists of a vast thickness of quartzitic and argillaceous beds. These purely sedimentary rocks are observed to pass laterally into a rock which in hand specimens resembles an eruptive rock.

This whole series contains no distinct beds of limestone, and wherever analyzed is remarkably free from carbonate of lime. Its lower limit is nowhere seen and, owing to the disappearance of the strata planes under extreme metamorphism, there is no possible mode of arriving at its total thickness. The upper limit, however, is sharply marked by an abrupt transition from the schists into a body of dark carbonaceous limestone. To this whole underlying group of schists and porphyroids we have given the title Koipato, from the Indian name of this range.[b]

Allowing for some slight difference in interpretation, Mr. King's characterization of the Koipato formation applies to the rocks on the western face of the range between Ellsworth and Downieville. Mr. King believed that the transition from sedimentary argillites to

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[a] U. S. Geol. Expl. Fortieth Par., Vol. II, p. 644.
[b] Idem, Vol. I, p. 269.

igneous rocks resulted from metamorphism, while in the case of the rocks near Ellsworth those which possess igneous structure are almost without doubt ancient volcanics, which pass above and below, and probably laterally, into shales, conglomerates, and water-laid breccias derived from these or similar igneous rocks. The whole series therefore is conceived to represent the products of a period of ancient volcanic activity.

The series is more indurated, altered, and oxidized than any of the Tertiary volcanic series, and no similar rocks are known in the Paleozoic of Nevada. Their correlation with the established Triassic formations is therefore plausible.

IGNEOUS ROCKS.

The oldest igneous rocks of the range are those just described as interstratified with the tuffs of the great ancient volcanic series. The only specimen examined is probably a hornblende-biotite-syenite-porphyry.

Next younger than these ancient volcanics come siliceous dikes, which are well exposed on the eastern face of the range, near Ellsworth. The most easterly outcrop encountered is an alaskite-porphyry[a] containing feldspar phenocrysts which are sometimes as much as 4 or 6 inches long. This resembles the granitic rock described south of Belmont. It is cut by several narrow dikes of finer-grained rock having the same composition, but not porphyritic. These siliceous dikes are intrusive into metamorphosed green rock just west of Ellsworth, the siliceous rock cutting the other in numerous dikes.

Covering the ancient volcanic rocks and the later alaskite dikes there is found, occupying the center of the mountain between Ellsworth and Downieville, a bed of volcanic ash. Above this, forming the crest of the range and constituting all the high peaks, is a massive, columnar-jointed volcanic rock. A specimen of this proved on examination to be hypersthene-aleutite.[b] In the western foothills, near Downieville, is also probably a patch of similar, comparatively young volcanic rock, and north of Downieville the low limestone mountains are succeeded after a few miles by a chain of lower hills, which are, in part at least, volcanic. These extend northward at least 10 or 15 miles. At the southern end of the Desatoya Range, as mapped by the Fortieth Parallel geologists, the rocks are all volcanic, enveloping the Triassic strata exposed in the region of New Pass Peak.

STRUCTURE.

Apparently the main structure of the range is anticlinal, the ancient volcanic series constituting the core, from which the overly-

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[a] Alaskite is a general name proposed for rocks consisting essentially of quartz and alkali feldspar, without essential ferromagnesian minerals. J. E. Spurr, Classification of igneous rocks according to composition: Am. Geol. Vol. XXV, 1900, No. 3.

[b] *Aleutite is the name proposed for a rock intermediate between andesite and basalt. J. E. Spurr, Classification of igneous rocks according to composition:* Am. Geol., Vol. XXV, 1900, No. 3.

ing limestones dip away on both sides. Just north of Downieville the low limestone mountains are separated from the main range by a shallow and relatively broad valley. The structure of these low mountains is anticlinal, and between this anticline and the one comprised in the main ridge is a syncline, in which the intervening valley lies.

ORES.

On both sides of the range there are ore deposits, once of great economic value, now largely abandoned. The mines near Ellsworth seem to be in the ancient igneous formation, and these old rocks show on exposed surfaces carbonate of copper and on fresh breaks copper pyrite. Between Downieville and the top of the mountains also there are ore deposits in the ancient volcanic series. At Downieville ores are found in the limestone, resulting apparently from replacement of the rock by sulphides.

PILOT MOUNTAINS.

East of the Excelsior Range, on the other side of Soda Springs Valley, lies a short but comparatively rugged mountain range which has a north-south trend, changing to northwest in its northern portion. On the south the foothills of this range merge into those of the Candelaria Mountains, and are separated from the northern end of the Monte Cristo Mountains only by a narrow gap. On the north, the Pilot Mountains pass into the volcanic hills of the Gabbs Valley Range.

The highest portion of the range is Pilot Mountain, which lies just east of Sodaville. On the west face of this mountain there is a bold scarp (very likely a simple fault scarp), which rises from a point which has an estimated elevation of about 6,000 feet above sea level. Below this point there are immense gulch dumps, or alluvial fans, covering the other valley detritus, and reaching several miles westward toward the center of the valley.

SEDIMENTARY ROCKS.

EARLY TERTIARY OR MESOZOIC SERIES.

Most of Pilot Mountain is made up of stratified rocks. At the base is a series of gray rocks which, on account of a slight east-west flexure, transverse to the general north-south line of folding, passes down to the north and south so as to be covered by the valley detritus. These rocks are hard to identify in the field on account of their altered character, but microscopic study shows them to consist mainly of volcanic tuffs, generally coarse, sometimes fine and slaty. They grade into solid lavas. A specimen of one of the lava sheets on examination seems to be andesite. In the field no sharp line can be drawn between the tuffs and the slaty lavas. These rocks are cut by many dikes of siliceous granite.

Overlying this gray tuffaceous series are reddish sandstones, shales, and conglomerates, which in turn are overlain by a considerable thickness of purer red sandstone and quartzite, which forms the summit of the mountains. An estimation of the thickness of the different rock series in this section gives 1,000 feet for the basal tuffaceous series, 1,000 feet for the sandstone, shale, and conglomerate series, and also 1,000 feet for the purer red sandstone series, making a total of 2,000 feet of red sandstone, shale, and conglomerate overlying 1,000 feet of the gray tuffaceous series.

Where the rocks immediately overlying the basal gray series were examined at the base of the mountain they were found to be red or white sandstone and quartzite, sometimes fine and calcareous, sometimes coarse and gritty. There is also much red sandstone conglomerate, indurated and squeezed. The pebbles of the conglomerate seem to be entirely of quartzite and chert. This reddish sandstone and shale series appears to extend northward several miles, until overlain by later volcanic rocks. On the south it does not extend so far, being overlain in the foothills of the Pilot Range along the road between Sodaville and Columbus by later horizontally stratified sediments.

The upper 2,000 feet of red sandstone, shale, and conglomerate is perhaps the same series as that described as occurring in the Excelsior Mountains, just across the valley to the west. The underlying gray tuffaceous series is not found in the Excelsior Mountains. Lithologically, some of the tuffs correspond to andesitic tuffs found in the folded Earlier Tertiary series of the Monte Cristo Mountains, 20 miles south of Pilot Peak. At the same time, the series has a very strong lithologic resemblance to the supposedly Triassic beds of the Ellsworth Range, into which the Pilot Mountains are almost directly continuous on the north.

Mr. H. W. Turner has recently reported Jurassic limestone and slate in the Pilot Mountains.[a] In a personal letter to the writer, Mr. Turner states that at the north base of the mountains he found abundant fossils in limestone, which were examined by Prof. J. P. Smith, of Stanford University, who pronounced them certainly Jurassic.

PLIOCENE.

On the southern side of Soda Springs Valley, horizontally stratified rolled gravels were found at an elevation of about 5,250 feet, and were referred to the Pliocene sediments of Shoshone Lake. Similar sediments undoubtedly exist at the base of Pilot Mountain, but they have been covered up by the enormous subsequent Pleistocene gulch dumps, which form a belt along the foot of the mountain. The material in these dumps manifestly represents the larger portion of that removed from the gulches which cut back into the scarp of the moun-

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[a] *Geol. Soc. Am.*, *Berkeley, Cal.*, *Dec.*, 1900. Report in Am. Geologist, Feb., 1901, p. 132.

tain above. The erosion of these gulches is, therefore, mainly Pleistocene.

At the southern end of the Pilot Mountains, along the road between Sodaville and Columbus, is a considerable area of horizontally stratified fine silts and hardened clays, with some volcanic ash beds. This formation constitutes the divide between Soda Springs Valley and Columbus Valley, and reaches as high an elevation as 6,000 feet, where it is overlain by a sheet of basalt. These beds are evidently the result of deposition in a still body of water, and are correlated with the similar Pliocene beds described elsewhere in this region.

IGNEOUS ROCKS.

PLEISTOCENE OLIVINE-BASALT.

At the southern end of the range, overlying probable Pliocene sediments, occurs a thin-bedded, dark, vesicular lava, which proves to be olivine-basalt. From its occurrence there is no doubt that this rock should be classified with the other Pleistocene basalts of the region.

GRANITIC ROCKS.

Pilot Mountain contains many branching dikes and irregular masses of intrusive granitic rock, similar to that across the valley in the eastern end of the Excelsior Range. A typical specimen, examined microscopically, proves to be a biotite-granite. The intrusives seem to be chiefly confined to the base of the mountain, and not to have reached, in very great quantity, the uppermost strata. The granite is accompanied by alaskite,[a] and in the vicinity of these intrusions are ore deposits, as in the case of the east end of the Excelsior Mountains; and the ore has probably had a genetic connection with the igneous rock.

MONTE CRISTO MOUNTAINS.

The Monte Cristo Mountains are comparatively short and low. They have a general north-south trend, and extend from the Pilot Mountains on the north to the Silver Peak Range on the south, with a total length of about 30 miles.

SEDIMENTARY ROCKS.

On the road between Columbus and Silver Peak there is a comparatively low gap in the Monte Cristo Range. In this gap are found low hills of white shale capped by a porous bed which, examined microscopically, proved to be a calcareous andesite tuff. From this rock a collection of poorly preserved fossil shells was made, which Dr. W. H. Dall was not able to identify with certainty. Dr. Dall thought the forms suggested a fresh-water origin. He found a

[a] Rock consisting essentially of quartz and alkali feldspar, without essential ferromagnesian minerals.

bivalve, which may be a *Sphærium*, and a gasteropod that may be a *Planorbis*. The shales contain frequent leaves and occasional coal seams.

These sediments are capped by volcanic rocks. In the low pass above referred to the immediately overlying rock is a light-gray tordrillite.[a] Above this comes andesite.

At the northern end of the Monte Cristo Range there appears to be a patch of stratified rocks similar to those just described, the intervening space being completely covered by lavas.

This series has been examined somewhat carefully by Mr. H. W. Turner, who has named it the Esmeralda formation. He finds that it is shown at various points in the Silver Peak Range, and that it comprises a considerable variety of sediments.[b] According to him the series exposed aggregates at least 2,000 feet, and is composed chiefly of sandstone, with some shale. The top is made up of lacustral marls and white shales. Mr. Turner collected from these rocks fossil shells, fish bones and scales, and dicotyledonous leaves, which were examined by Dr. J. C. Merriam, Prof. F. A. Lucas, and Dr. F. H. Knowlton. Dr. Merriam found that the fossil shells indicate an early Miocene or a late Eocene age for the beds, and Dr. Knowlton found that the plant remains indicate a Middle Tertiary age. The fish remains, so far as yet studied, do not seem determinate.

The writer has observed in the region south of here, notably in the neighborhood of Death Valley and in the Mojave Desert, upturned Tertiary sediments which he is inclined to correlate with the beds of the Esmeralda formation in the Silver Peak and Monte Cristo Mountains.

IGNEOUS ROCKS.

The greater portion of the Monte Cristo Mountains is covered by volcanic rocks. In general, dark basic lava seems to overlie lighter-colored siliceous lava.

DESERT MOUNTAINS.

The Desert Mountains form an irregular group which runs from the southern end of Mason Valley southeastward to near the northwestern end of the Gabbs Valley Range at the northern end of Walker Lake. In general these mountains have slight relief, although north of Mason Valley the peaks reach a considerable height. At the southern end the mountains change into low mesas of brilliant color.

These mountains are composed entirely of well-bedded volcanic rocks. At the extreme northwestern end specimens examined prove to be biotite-hypersthene-andesite. Along the southeastern end, near

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[a] Tordrillite differs from a rhyolite in being more siliceous and containing no essential dark minerals. J. E. Spurr, Am. Geol., Vol. XXV, 1900, No. 3, p. 230.

[b] *The Esmeralda formation:* Am. Geol., Vol. XXV, 1900, p. 168.

the head of Walker Lake, the old beaches of the Pleistocene Lake Lahontan may be traced.

GABBS VALLEY AND GABBS VALLEY RANGE.

Gabbs Valley is a broad, flat-bottomed basin, almost completely surrounded by irregularly distributed volcanic mountains. The higher mountains to the south of the valley constitute the Gabbs Valley Range, which extends from Walker Lake southeastward for about 40 miles to the Pilot Mountains. The topography of this range, as well as of the hills on the north side of the valley, is comparatively primitive, the valleys being regular and in general not very deeply cut, recalling the erosion topography of the supposedly Pliocene lake deposits of Pleasant Valley in the Snake Range.

SEDIMENTARY ROCKS.

EARLIER TERTIARY MARLS.

Near the center of the valley, just east of the low mountain spur which crosses it, and on the Reese River road, there are low ridges of gray, stratified marl containing leaf remains, alternating with gravels and more solid conglomerates. Some of the conglomerate contains comparatively abundant silicified wood. The conglomerate, when examined microscopically, proves to be volcanic. The pebbles are made up in part at least of spherulitic glass. Some pebbles contain phenocrysts of feldspar, of species indicating that the lava is andesitic, in a glassy matrix containing broken feldspar and biotite. Some of the shaly beds associated with the conglomerate are feldspathic tuff, made up of fine fibrous material, with larger broken fragments of feldspar and some shreds of biotite. These beds strike north and south and dip about 8° E.

No fossils were obtained from these beds. The locality is, however, at a higher altitude than that of the Pleistocene lake which, according to Professor Russell,[a] covered the lowest part of the valley just west of here. Also, the beds seem to show a general tilting, and since, according to Mr. King,[b] the last marked folding in this area was post-Miocene, these beds are very likely pre-Pliocene. They have the aspect of lacustrine marls. Lithologically, they coincide with the descriptions given by Mr. King of his typical Truckee Miocene, which consists of sandstones, conglomerates, and tuffs at the base, with an enormous thickness of volcanic tuffs at the top, the whole series being as much as 2,000 or 3,000 feet thick. The typical Miocene localities of King are situated near here to the north. Therefore the beds under consideration are provisionally correlated with those described by Mr. King. They have also a general resemblance in their nature, derivation, degree of induration, and especially in their

[a] Mon. U. S. Geol. Survey Vol. XI, Pl. XLVI. [b] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 455.

containing silicified wood, with the early Tertiary series of the Silver Peak region, closely adjacent to the south. (See p. 185.)

PLEISTOCENE.

In the lowest portion of Gabbs Valley, west of the Tertiary marls just described, is a broad alkali flat or playa, covered with smooth, hard mud. This was perhaps the bottom of a lake inclosed in the Gabbs Valley Basin. As mapped by Professor Russell, it was contemporaneous with the great Lake Lahontan, but separated from it.

At the base of the volcanic mountains there is a continuous apron of detrital material sloping away at an angle of about 3½° for a mile or two toward the middle of the basin. As in the case of the similar alluvial deposits investigated by Mr. Russell,[a] these aprons seem to be older than the great Pleistocene lakes.

The effect of eolian action, of importance everywhere in the Great Basin, is very conspicuous in certain portions of Gabbs Valley. The wind-blown sands have in many places accumulated in considerable mass.

IGNEOUS ROCKS.

Most of the mountains surrounding Gabbs Valley, including the Gabbs Valley Range, are volcanic. These rocks represent a variety of species.

Just east of the hot spring in the valley the road passes through a gap in the mountains about 1,500 feet deep, the sides of which rise at an angle of about 50°. The rock at this point varies from moderately fine to moderately coarse, but it is, nevertheless, always holocrystalline. It is massive and vertically jointed, yet has a distinct horizontal bedding, and a little northeast of here it seems to be underlain by ash. It is therefore probably effusive. A single specimen of this rock, examined microscopically, proves to be a hornblende-biotite-quartz-monzonite.

On the mountain ridge which separates Gabbs Valley from Walker Lake Valley the lavas which dip eastward into the former basin at angles of 10° or more, in color gray or oxidized bright red, prove to be biotite-, hypersthene-, and hornblende-aleutites and andesites. On all the mountains to the north of here, which were not visited, there appears to be a basal light-gray or red lava, which forms the highest peaks, underlying a dark-brown or black lava which forms the fringes of the mountains and sometimes constitutes a cone yet only slightly defaced.

Where the road crosses the extreme western end of the Gabbs Valley Range, overlooking Walker Lake, the lavas are mixed and the hills variegated, the colors being bright red, yellow, gray, greenish

[a] Mon. U. S. Geol. Survey Vol. XI, p. 256.

yellow, white, and black. In general a light-gray lava is overlain by dense black flows. The former proved to be biotite-andesite, while the latter is augite-basalt. A little farther, biotite-rhyolite was found, apparently underlying the basalt.

EXCELSIOR RANGE.

The name Excelsior Range is applied to a short, rather irregular group of mountains which lies south of Walker Lake, and, unlike the most of the ranges of this region, runs in a general east-west direction, cutting off the southern end of Walker Lake Valley and extending from the southern end of the Walker River Range eastward to Soda Springs Valley. The entire length of the range is only about 30 miles. The main range has to the north of it several high spurs which run off at right angles and connect with a lower east-west ridge parallel to the main one, farther north. To the south also a number of north-south spurs connect the Excelsior Mountains with the Candelaria Mountains. The main range is terminated on the east by a bold scarp overlooking Soda Springs Valley, corresponding to the west-facing scarp of the Pilot Mountains on the other side.

These mountains were crossed by the writer on the road between Hawthorne and Sodaville, which leads through Excelsior Flat.

SEDIMENTARY ROCKS.

LIMESTONE SERIES (EARLY TERTIARY?).

If one travels along the above-mentioned road from Walker River Valley eastward, he finds, after passing through a belt of lava which constitutes the foothills, an area of thin-bedded, shaly, sometimes compact, blue limestone. This limestone is overlain by a lava sheet, and near the contact is baked and silicified to a greenish or brown jasperoid containing segregated nodules of silica. The stratification is nearly horizontal, but shows local contortion and horizontal faulting, suggested breaking and shoving by the overriding lava sheet.

Near the contact, partly in the blue shaly limestone, partly in the same rock transformed into jasperoid by the contact metamorphism, were found fossils. Mr. T. W. Stanton, of the National Museum, reports on these as follows:

Fossil lot No. 46, from the Excelsior Range, road between Hawthorne and Sodaville, evidently represents two distinct beds, one a hard brown siliceo-argillaceous rock and the other a dark-blue limestone. The former contains several specimens of a *Corbula*, another undetermined bivalve, and a very imperfect Gasteropod that may be a *Natica* or a *Vivaparus*, the generic character not preserved. These are probably not earlier than Cretaceous, and they may be Tertiary.

The blue limestone fragments yielded a small *Neritina*, a *Hydrobia* (?), an *Astarte* (?), and several imperfect specimens of two or three other small bivalves. These fossils have a Tertiary aspect. They are certainly not older than Cretaceous.

In answer to a query as to the conditions of deposition indicated by the fossils Mr. Stanton writes:

> The fossils in lot 46 are either marine or brackish-water form, not fresh water. If I could be sure that the bivalve I have called *Astarte* (?) really belonged to that genus there would be no doubt that they are marine. The other genera recognized live in both salt and brackish water.

To the east this limestone forms a well-defined anticline, with a north-south axis, and with dips of 20° to 30° on both sides. Still farther east the limestone is again overlain by the volcanic rock which encircles this area.

In the bottom of Excelsior Flat, near its eastern side, probably the same limestone series is found, but more altered and crushed and veined by dynamic action. Badly preserved fossils were collected from this rock, but could not be identified.

The thickness of this limestone series was roughly estimated at 2,000 feet.

SANDSTONE-SHALE SERIES (EARLY TERTIARY OR MESOZOIC?).

Along the western border of Excelsior Flat is found a belt of red sandstone which underlies the lavas. This sandstone belt is continuous to the low mountains south of here, where it passes upward into a series of gray stratified rocks. Farther east the sandstone series, with the overlying gray rocks, seems to overlie the probable Tertiary limestones which outcrop along the eastern portion of Excelsior Flat, the older rock being apparently the core of an east-west striking anticlinal fold, and the sandstone series forming the northern limb. On the southern limb, which comprises the main ridge of the Excelsior Mountains, the bulk of the rocks seem, as viewed from a distance, also to belong to the stratified red sandstone and shale series.

Following the road farther east, the transverse spur which runs northward from the main ridge of the Excelsior Mountains exhibits the same east-west striking anticline. Along the axis a canyon has been cut through the spur, and here are exposed red sandstones, with much red, yellow, brown, and green dense siliceous shales. No fossils could be found. The rocks here stand, in general, nearly vertical, and are crumpled and faulted. South of here the rocks have a southerly dip, first steep, then shallowing, while to the north the rocks belonging to the same series have for a considerable distance a northerly dip, which afterwards reverses so that a body of underlying gray shale, which may belong to the probable Tertiary limestone series, comes into the visible section.

From the data above noted, we appear to have a series of red sandstones and quartzites, with some shales and conglomerates, having a roughly estimated thickness of 1,500 feet. These are overlain by a series of red-gray sandstones, shales, and conglomerates about 2,000 feet in thickness, making a total of about 3,500 feet. These rocks

seem to overlie the probable Tertiary limestones and are folded together with them. The exact contact of the two series, however, was not found. No such sediments as this sandstone-shale are known in the Paleozoic section, and therefore the rocks would, without any other consideration, at once be considered as Mesozoic or Tertiary. In the region just south of here a series of folded shales and tuffs has been described by Mr. Turner[a] under the name of the Esmeralda formation and is probably Miocene, possibly reaching back into the Eocene.

This series, when observed by the present writer, struck him as resembling in a general way the thin sandstones and parti-colored shales of the Excelsior Range section, although the latter are distinctly more highly indurated and altered.

Rocks similar to the sandstone-shale series of the Excelsior Range form a large portion of Pilot Mountain, just to the east of here, across Soda Springs Valley. As noted in the description of the Pilot Range, Mr. H. W. Turner found Jurassic fossils in some of these beds.

It is therefore not certain whether the sandstones and shales of the Excelsior Mountains are Tertiary or Mesozoic, and they may be partly one and partly the other.

While the series of tuffs, sandstones, shales, and conglomerates of the Excelsior Range may possibly be the equivalent of the somewhat similar strata of the Esmeralda formation near Silver Peak, the limestone of the former locality is not represented in the latter. This limestone also separates itself from the probable fresh-water Esmeralda formation in that its fauna denotes a probable marine origin. In this respect, also, it seems to be different from the rest of the known Tertiary strata, which extend in a more or less continuous belt from this district south into the Mohave Desert, and the present aspect of our knowledge indicates that it represents a period during which conditions were quite different from those which followed.

PLIOCENE.

On the western side of Excelsior Flat the lava is underlain by a solid but friable deposit, consisting of ash and pumice, having the appearance of being waterlaid. This occurs at an elevation of about 5,500 feet. In the valley below and to the east of this are less consolidated, horizontally stratified gravels, containing pebbles of lava and reaching up nearly to the same elevation.

On the eastern flanks of the Excelsior Mountains, overlooking Soda Springs Valley, there was noted, at an elevation of 5,250 feet, horizontally stratified gravels and volcanic tuffs, lying unconformably against the folded Tertiary series and partially consolidated. The regular stratification of these deposits suggests that they are lake

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[a] Am. Geol., Vol. XXV, 1900, p 168. See also this report, p 185.

sediments, and they are probably to be correlated with similar sediments found all over the region north and west of here, which have been called Pliocene.

IGNEOUS ROCKS.

LAVA.

Along the road between Hawthorne and Sodaville, which passes through Excelsior Flat, there is, on the west border of the hills, a belt of fine-grained lava, which forms broad, slightly dissected mesas. A specimen of this lava proved to be pyroxene-olivine-basalt. It occupies a large area, inclosing the body of probable Tertiary limestone, which it overlies, and toward the east forms a considerable portion of the main ridge of the Excelsior Mountains, of the spurs which run north from it, and of the parallel east-west ridge with which these spurs connect. It overlies the probable Tertiary sandstones and shales and the stratified, water-laid tuffs and gravels of the Pliocene. South of the main range the earlier Tertiary series is again overlain by slightly dissected lava, and this lava runs southward into the Candelaria Mountains, where a prominent peak has the aspect of a slightly denuded volcanic cone.

The fact that this lava overlies all the stratified rocks, even the supposedly Pliocene gravels, together with its very slight erosion, shows that it is very young, probably early Pleistocene. The composition of the lava bears out this reasoning, for it is probably to be correlated with the Pleistocene basalts described in other ranges.[a]

GRANITIC ROCKS.

As seen from Excelsior Flat, a considerable portion of the highest part of the Excelsior Mountains to the southwest consists of gray, rugged-weathering granitic rocks. At the abrupt eastern end of the main range the earlier Tertiary sandstone and shale series is contorted and apparently cut by granitic dikes.

STRUCTURE.

To the north of the main ridge, the general east-west valley, which is in part occupied by Excelsior Flat, seems to lie along the axis of an anticlinal fold with east-west strike. The main ridge lies on the southern limb of this fold, while the minor ridge lying north of the valley and parallel to the main one, is on the northern limb.

Northwest of Excelsior Flat the area of probably Tertiary limestone first described[b] forms one of the north-south spurs which run at right angles to the main range. The structure of this spur is anticlinal, but the strike of the fold is north and south.

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[a] J. E. Spurr, Succession and relation of lavas in the Great Basin region: Jour. Geol., Vol. VIII, p. 636.

[b] See p. 109.

ORES.

There has been considerable mineralization in the Excelsior Mountains. On the west side, along the road traveled, there has been mineralization in the limestone near the contact with the overlying lava. Farther east the red sandstones are found to be bleached and to contain disseminated copper minerals. On the eastern end of the main range are ore deposits, associated with crumpling of the strata and probably with granitic dikes.

RÉSUMÉ.

The rocks of the mountains are probably Early Tertiary limestones, together with a series of sandstones and shales with some conglomerates. The relative age of the limestones and sandstone shales is uncertain. These two series were folded together. While the main folds trended east and west, a minor set had north-south axes. At about the same time came the intrusion of granitic rocks as dikes and larger masses; the ore deposition was also probably nearly contemporaneous. After this came deep and long-continued erosion, bringing about the present topography and followed by the formation of the Pliocene lake. Finally this lake receded and great sheets of basalt were poured out.

CANDELARIA MOUNTAINS.

The term Candelaria Mountains is here applied to an irregular group, reaching from the California-Nevada State line eastward to the Columbus Valley. It lies just north of the White Mountain range and south of the Excelsior Mountains.

SEDIMENTARY ROCKS.

CAMBRIAN.

Mr. F. B. Weeks, who visited the mountains in 1899, has informed the writer of the existence of a considerable thickness of quartzite and limestone (see Pl. I). No identifiable fossils were found.

CARBONIFEROUS.

On the road between Columbus and Candelaria there occur dark-gray, nearly black, quartzites, and stretched conglomerates, with some coarse sandstones and nearly white fine-grained chert. Mr. H. W. Turner has kindly supplied the writer with the following note concerning the discovery of Carboniferous fossils in this rock:

I am indebted to William Grozenger for information as to this locality, which lies 8 miles northwest of Columbus by the trail to Candelaria, at an elevation of about 4,900 feet. Similar fossils also occur in the gulch just north of this point at

an elevation of about 5,200 feet. These fossils were referred to Mr. Charles Schuchert, of the United States National Museum, who reports that the collection contains two Carbonic species, a *Productus* and a *Spirifer*. Both are specifically undetermined at present. The *Spirifer* (apparently a new species) belongs to the *S. cameratus* section, fossils recognized as characteristic of the Upper Carbonic. The *Productus* is apparently identical with one from the region north of Mount Shasta, in California, also associated with Upper Carbonic species. These forms remind one more of the Carboniferous fauna found in the Shasta region than of the Carboniferous farther east.

EARLIER TERTIARIES.

Adjoining the Carboniferous rocks to the northeast, and probably overlying them is a comparatively small area of brown, yellow, sometimes purplish, limy and sandy shales, argillaceous fine sandstones, and thin-bedded brown and yellow aphanitic limestones. This series strikes N. 65° E., and dips 65° NW. It is probably identical with the rocks of the Esmeralda formation a few miles to the south, in the southern end of the Monte Cristo Mountains. At one place the upturned edges of the stratified rocks are overlain by a thin sheet of siliceous rock, so glassy that the microscope does not show its true character, but it is probably rhyolite and susceptible of correlation with the rhyolite overlying the sedimentary rocks in the Monte Cristo Mountains.

PLIOCENE BEDS.

At the gap which separates the Pilot Mountains from the Candelaria Mountains, just north of Candelaria, occur certain horizontally stratified clays and sands which have already been mentioned, in describing the Pilot Mountains, as belonging to the group of Pliocene sediments.

IGNEOUS ROCKS.

Overlying the Pliocene sediments not far north of Candelaria, thin sheets of olivine-basalt were found (Pleistocene). South of here, overlying the stratified beds of the Esmeralda formation, were found the sheets of glassy rhyolite above mentioned. West of Columbus and Candelaria, a large part of the range appears to be composed of red and gray lavas overlying and often concealing the sedimentary rocks. As seen from Sodaville, the northern part of this mountain group is also chiefly volcanic, the topography showing such smooth, mesa-like forms, and so little erosion that the rocks were considered as probably belonging to the Pleistocene lavas. A prominent peak in the central portion of the Candelaria Mountains has the aspect of a little denuded volcanic cone.[a]

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[a] These observations have been confirmed by Messrs. Turner and Weeks, who visited the range separately the same year as did the writer. Mr. Turner states that the hills north of Benton are also all lavas.

WALKER RIVER RANGE.

The Walker River, or Wassuck, Range is a straight, bold ridge of mountains, rising immediately from the west shore of Walker Lake. It has a trend a little west of north and a length of about 60 miles. It is separated on the north from the volcanic Desert Mountains by the Walker River Valley, and on the south it passes into the irregular Excelsior Mountains. Throughout most of its course the range is characterized by the comparatively gentle slope of the west side and a steep scarp on the east.

IGNEOUS ROCKS.

Almost all the rocks of the Walker River Range are igneous. Those on the steep eastern face are generally granular, and those on the west side typical volcanics.

GRANULAR ROCKS.

Just west of the Indian agency at the upper end of Walker Lake, the rock of the mountains is chiefly a coarse-grained biotite-granite. Farther north, near the point where the road crosses the range, biotite-granite-aplite, of a distinctly more siliceous variety than the first, occurs in conjunction with great masses of alaskite-aplite.

On the road which crosses the range, at a point southwest of Hawthorne, the summit and greater part of the mountain range appears to be also of decomposed biotite-granite. Between these two localities the granite is probably nearly or quite continuous.

Underlying the biotite-granite, at the point first described, is a dark rock, specimens of which proved to be hornblende-quartz-syenite and biotite-hornblende-quartz-monzonite. The granite is shown by its branching dikes to be intrusive into the more basic rock. Both rocks are cut by dikes of alaskite, which grows very siliceous and runs out in places to nearly pure quartz.

In the cream-colored mountain of granite and alaskite around which the road turns in crossing the range, the alaskite is evidently younger than the siliceous granite, into which, however, it passes by transitional stages as regards its composition. The granite sometimes contains large feldspar phenocrysts, similar to those of the rock near Belmont and near Ellsworth.

At the pass southwest from Hawthorne, the biotite-granite which occupies the summit of the mountains is succeeded farther east by metamorphosed igneous rocks, probably altered by dynamic movements. These rocks lie along the face of a bold, eastward-facing scarp. As examined microscopically, they consist of aposyenite-porphyry, apogranite, and apoalaskite, with some biotite-rhyolite, which may be later than the others. These metamorphosed igneous rocks are confused with some highly altered limestones and quartzites.

LAVAS.

On the west side of the cream-colored mountain which lies northwest of the north end of Walker Lake, on the road across the range, the granular rocks, already described, pass under and into gray and red volcanics, which dip 30° to 45° SW. away from the mountain. About the point where the granular rock gives place to the evident volcanics, specimens were collected, which proved to be alaskite-porphyry and tordrillite, the latter with a finely cryptocrystalline groundmass. Overlying these siliceous rocks was found augite-biotite-aleutite. West of this point, near the summit of the range, the prevalent rock is biotite-andesite, containing many angular fragments of a darker lava. The whole western side of the mountains is volcanic.

IGNEOUS ROCKS SHOWING TRANSITIONS OF TEXTURE.

In a small butte (Mason Butte) which emerges from the Pleistocene valley deposits to the west of the northern part of the Walker River Range, a few miles south of Wabuska, an intersecting series of igneous rocks was studied. The butte presents the appearance of a typical volcanic rock, being distinctly and thinly bedded and of red and gray colors.

Upon examination the rocks are found to be in part granular and in part fine grained and porphyritic, the different textures alternating in conformable beds. Examined microscopically, the coarse-grained rocks are hornblende-biotite-quartz-diorites, while the fine-grained ones are hornblende-biotite-quartz-andesites. The chemical composition of the two rocks is also nearly the same. Sometimes the coarse-grained and the fine-grained types appear in the same bed, one apparently being formed at the same time as the other; generally, however, the beds are separate.

The hypothesis adopted by the writer is that these rocks are the roots of old volcanic flows which have been exposed by the removal of the overlying portions of the lava through the erosion of Walker River, in whose valley the butte lies. The whole appears to have been an igneous mass in process of slow flowage, some streaks of which crystallized rapidly, with the texture of true lavas, while between them portions of the same magma crystallized more slowly, as granular rocks.[a]

Facts suggesting similar transitions of texture were noted within the main Walker River Range, but are not described on account of insufficient evidence.

SEDIMENTARY ROCKS.

PLEISTOCENE.

Professor Russell has described the history[b] and the sediments of the Pleistocene Lake Lahontan, an arm of which occupied the valley

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[a] *For a fuller statement of this problem see* J. E. Spurr, Variations of texture of certain Tertiary igneous rocks in the Great Basin: Jour. Geol., Vol. IX, p. 586.

[b] *Mon. U. S. Geol. Survey* Vol. XI.

of the present Walker Lake. The writer also observed these sediments as well as older stratified deposits, which reach higher up in the mountains. The line between the Pleistocene and the Tertiary has not been closely drawn in this region, and probably a portion of those deposits older than the Lahontan sediments are still Pleistocene, but at present the writer will include under that head only the deposits of the lake described by Russell.

In the valley of Walker Lake the depth of the Pleistocene Lake Lahontan at its highest stage was 225 feet. At the upper end of the present Walker Lake the elevation is 4,120 feet above sea level, which would make the surface of Lake Lahontan at this point 4,345 feet. At about this altitude, as measured by the barometer, the writer found a heavy terrace, and about 200 feet above this a still heavier one, the top of the main terrace being about 4,600 feet high. These terraces are constructional and show a rude horizontal stratification. They are composed largely of gravels and huge bowlders from the adjacent mountains. At another point, farther north, the altitude of this same chief terrace was determined as 4,675 feet. On the opposite side of the valley, on the slopes of the Painted Mesa (which forms part of the Desert Mountains), corresponding deposits may also be seen, taking the form of inclined slopes or ancient beaches rather than of sharply cut terraces.

PRE-LAHONTAN SEDIMENTS.

About 100 feet above the heaviest terrace just mentioned is a lesser constructional terrace, and about 400 feet higher there is on the mountains a rock-cut bench which is probably also a water line. This rock-cut bench is at an altitude of about 5,100 feet, or about 700 feet above the surface of the ancient Lake Lahontan, while the constructional terrace below it is about 300 feet above the old surface. Crossing the southern end of the range, coarse, horizontally stratified material, consisting of little assorted volcanic rock, is found to the summit, where it forms hills 400 or 500 feet high, reaching up to an altitude of about 5,730 feet, or 1,385 feet above the surface of Lake Lahontan.

On the western side of the range, at the point where the road crosses due southwest from Hawthorne, stratified gravels are found up to a height of 7,100 feet. These deposits seem to be water-laid. They are evidently pre-Lahontan, and if formed in a lake occupied a body of water which was the ancestor of the Pleistocene lake, but of vastly greater dimensions and probably of longer life.

From reasons entailed in the correlation of these gravels with others throughout the region these deposits are provisionally classified as Pliocene.

SMITH VALLEY RANGE.

The name Smith Valley Range may be applied to a low and narrow mountain ridge, which on the north merges with the Pine Nut Range,

and on the south spreads out broadly into a series of volcanic mesas, which connect farther south with a spur of the Sierras north of Lake Mono. The range as thus defined separates Mason Valley, on the east, from Smith Valley, on the west.

IGNEOUS ROCKS.

Smith Valley Range is essentially volcanic. At the northern end, where it merges into the Pine Nut Range, specimens of the lava, forming comparatively well-dissected mountains, are found to consist of hypersthene and biotite-andesite, with some biotite-dacite. Southward from here the range is evidently volcanic, but it was not examined closely except in the region of Dalzell Canyon, which separates the southern part of the range from the Sweetwater Mountains, farther west.

In Dalzell Canyon the oldest formation consists of granite and rhyolite, and is altered and jointed. Overlying this is pyroxene-hornblende-andesite, and still higher are comparatively slightly eroded mesas of more siliceous andesitic rock, or hornblende-biotite-latite.

On the road which cuts across the low southern end of the range east of Sweetwater, following the upper part of the East Walker River Valley, the siliceous andesite and latite flows are succeeded on the east by more basic thin-bedded andesitic or basaltic lava, largely glassy. This overlies sands, clays, and conglomerates, which will presently be described as probably Pliocene. It has flowed into and dammed up the valley eroded in the earlier lavas. It is therefore the latest of all and is probably Pleistocene. Farther east this same glassy lava occupies a considerable area in the bottom of the broad Walker River Valley, and forms broad mesas on the flanks of the Smith Valley Range on the west and the Walker River Range on the east, and, reaching around to the south, forms a large part of the hills between the Walker River Valley and Mono Valley. At the southern end of Walker River Valley, a few miles north of Aurora, is a little-defaced volcanic cone of red lava, which probably belongs to the same epoch. This has been called the Aurora Crater on the topographic map accompanying Professor Russell's paper on Lake Mono.[a] These lavas everywhere overlie the stratified gravels which occur in the southern part of the Walker Lake Valley, in the same manner as already mentioned.

South of here, in the basin of Lake Mono, Professor Russell[b] has described various lavas, including hypersthene-andesite verging upon basalt, and rhyolite, which are evidently Pleistocene. These lavas belong to the same class as those just described, and seem to correspond with the thin flows capping the Pliocene gravels near Wellington on the Sweetwater Range, and also to the thin flow of basalt which

[a] Eighth Ann. Rept. U. S. Geol. Survey, Pt. I, Pl. XVII.
[b] *Ibid.*, pp. 374, 375, 377, 380.

constitutes the latest volcanic rock in Eldorado Canyon in the Pine Nut Range;[a] but in the district under immediate consideration we have a vastly greater amount of Pleistocene volcanic action than was observed anywhere else in the region.

SEDIMENTARY ROCKS.

Just south of Dalzell Canyon were found well-stratified arkoses and little-worn conglomerates, containing chiefly angular fragments. These seem to cover the whole of a broad upland valley, to its abrupt end at the base of the Sweetwater Mountains, at an elevation of something over 7,000 feet. As one goes southeastward from here, passing Sweetwater post-office and proceeding down the valley of Walker River where this cuts across the range, one finds, at an elevation of 6,500 feet at least, and below, well-stratified, washed, and assorted, horizontally or slightly cross-bedded sandstones, arkoses, and gravels. These rocks are often firmly consolidated, though friable, and resemble the sandstones near Carson, as exposed at the State prison.[b] The pebbles in the gravels are evidently derived from the andesite which is the main rock of the Smith Valley Range. Farther west, on the slopes of the hills facing the main Walker River Valley, a section of these deposits 100 feet thick was examined. Near the bottom were found sandy clays, which may be in part water-laid volcanic ash. Farther up come hard gravels, the well-rolled pebbles comprising various varieties of hornblende- and mica-andesite. Above this comes a compact gray sandstone, also made up of volcanic débris and containing fragments of white decomposed pumice. Capping the sedimentary rocks and overlying them, with a considerable angle of divergence, comes a thin sheet of andesitic or basaltic lava with glassy base. The top of this section has an altitude of about 6,150 feet. A short distance away from this section the highest sandstone reaches an altitude of about 6,350 feet and is exposed as a simple bench in the mountains, the overlying lava having been eroded back from it. Along the northern slopes of the mountains which form the southern end of the Walker River Valley, northwest from Aurora, are continuous benches, the best marked of which can be little less than 7,000 feet in height. Below this are other sharp smooth benches of horizontal sandstone. The comparatively recent volcanic cone above referred to, lying northeast from Aurora, is benched up to 6,700 or 6,800 feet, but not higher. These terraces appear to grow somewhat higher to the south. The whole valley here is covered with the sandstones above described, which have been considerably eroded. At least 700 or 800 feet of this sedimentary series is exposed.

On the road which crosses the southern end of the East Walker River Valley and goes over the Walker River Range to Hawthorne,

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[a] See pp. 121 and 126. [b] See p. 124.

horizontally stratified gravels, apparently belonging to the same series as the sandstones above mentioned, occur, frequently overlain by glassy and slaggy andesitic or basaltic lavas, up to a height of 7,100 feet, where they give way to a fresh lava, above which all is decomposed granite.

All these comparatively recent horizontal sediments are provisionally classed as Pliocene.

PINE NUT RANGE.

TOPOGRAPHY.

The Pine Nut Range lies immediately east of the Sierra Nevada, and has much of the bold irregular topography of that range. As contrasted with the mountains of the more arid regions farther east, it is distinguished by deeper dissection, affording more profound canyons and more abrupt cliffs. The eastern face of the range is steep, the western side in general less abrupt.

Wherever this range was visited, numerous springs were observed, and the dissection seemed to be largely the result of water derived from these sources. The springs seem to be arranged, in part at least, along north-south lines, which are probably lines of fracture. These lines are deeper than the regions between, which stand up as ridges; but whether these ridges are directly due to displacement, or have been left as such by the erosion of depressions along the lines of spring water, is uncertain.

On the western side, between Dayton and Carson, the peculiarly wild and rugged topography is caused by the Carson River and its mountain tributaries which, in late Tertiary or Pleistocene time, have dissected the mountain and the adjacent plateau-valley.

IGNEOUS ROCKS.

Nearly the whole mass of the range is igneous. The rocks were studied principally along two sections, one across the range southeast from Dayton and the other on the road between Wellington and Genoa.

In the eastern part of the first-mentioned section, in the lower mountains which here lie to the east of the main range and are connected with the northern end of the Smith Valley Range, chiefly andesitic rocks were found. The andesite contains different ferromagnesian minerals, including hornblende, augite, hypersthene, bronzite, and biotite. Occasionally biotite-dacite or quartz-andesite is found. Where erosion has cut deeply into the lava, coarser, denser, more massive, and more porphyritic forms are exposed. At the bottom of one of these canyons the lava is a fine-grained diorite-porphyry, while farther up it is hypersthene-bronzite-andesite with some dacite.

Farther west, on the eastern scarp of the main range, occur gran-

ular rocks. These, when examined microscopically, turned out to be hornblende-biotite-granite, sometimes porphyritic, and alaskite. The same granular siliceous rocks are exposed nearly to the summit, and they occur also on the western side of the divide. Here they are overlain by hornblende-, augite-, and hypersthene-andesites.

About halfway down the mountains, in Eldorado Canyon, where the road leading to Dayton runs, there are hills of gently folded gravels and coarse clays, the gravels being derived almost entirely from the andesites. They are exposed best in the arroyos, where they are overlain unconformably by 8 or 10 feet of stratified bowlders and soil, which represent the recent stream accumulations. Farther down the canyon is a volcanic breccia with rounded andesite bowlders, probably water-laid. This breccia is followed by thin flows of slaggy white lava, which contains numerous included angular fragments of andesite; these flows are interbedded with ash. The present canyon has been worn down through this breccia, ash, and porous white lava deposit. In several places a thin sheet of basalt has been poured out after the development of the present topography (fig. 8). This sheet

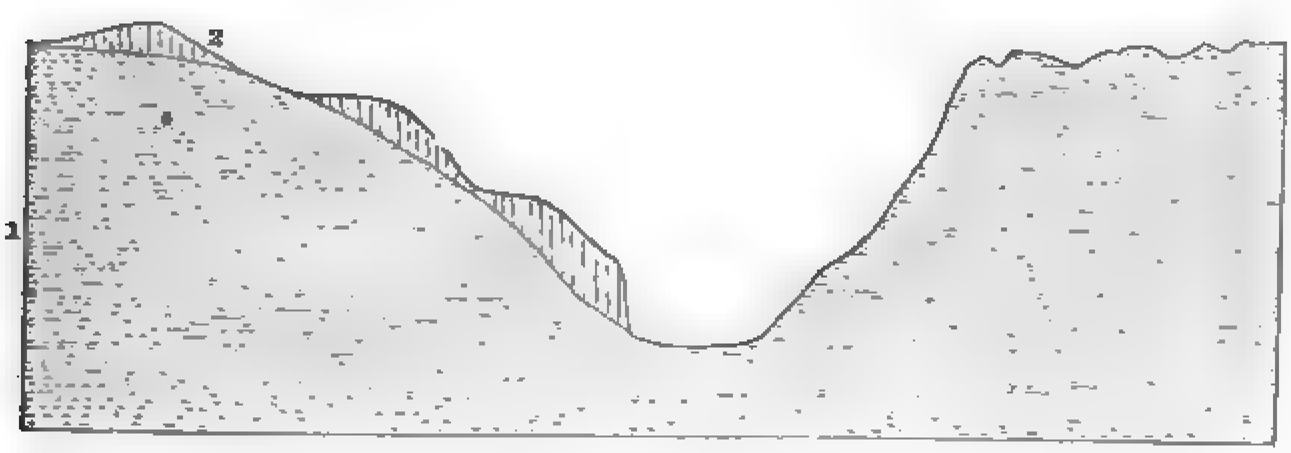

FIG. 8.—Section of Eldorado Canyon, Pine Nut Range.
1. Stratified rhyolite ash. 2. Basalt

also occupies the tops of some of the neighboring hillocks, which have been separated from one another by erosion subsequent to the last volcanic outbursts.

In the canyon of the Carson River, a few miles southwest of Dayton, the stream has cut down 400 to 800 feet, exposing lavas like those in Eldorado Canyon. The uppermost of these flows is a white, little-compacted rhyolite, while beneath it are large masses of a rock recognized in the field as lava, which on microscopic examination appears to be monzonite-porphyry. This is perhaps a coarser variation of andesite.

Between Dayton and Wellington the Pine Nut Range is mainly igneous. The central ridge has a massive aspect in general, and is probably made up of the granitic rocks.

Where the road between Genoa and Wellington crosses the range, hornblende-biotite-andesites occur on the western slopes. As in Eldorado Canyon, the whole system of gulches has been cut in this lava.

Near the summit of the low pass on this road were found cliffs of a dense, massive, volcanic breccia with horizontal bedding and containing pebbles of rhyolite only. Some distance farther up, apparently belonging to the same series as the breccia, was found an ancient, apparently water-laid tuff, which microscopic examination shows to be rhyolitic, with above it a bed of coarse volcanic grit, and still higher a bed of volcanic conglomerate with large well-rounded pebbles of biotite-rhyolite and a matrix derived from the same rock. A short distance farther the rocks from which these detritals are derived were found in place in a hill to the north of the valley and to the east of the pass. This rock shows many and great variations, passing from a fine-grained aphanitic rhyolite to coarse granite and alaskite, and these variations are arranged in thin bands.

These are essentially quartz-feldspar rocks, generally containing biotite. They comprise biotite-rhyolite, fine-grained granite-porphyry, medium-grained biotite-granite, coarse-grained alaskite and granite-aplite, and one specimen was a fine-grained quartz-monzonite-porphyry. These different varieties present, texturally and structurally, almost perfect transitions from one to another, ranging from coarse granites through the granite-aplites and porphyries to the rhyolite, and the development of the different structures from the fine-grained rhyolite is very clear and instructive. Only one band was found which did not belong to the general granitic series. This was a band of dark-green slaty rock, which, when examined, proved to be probably hornblende-andesite; yet this rock does not appear to be intrusive, but to form a band or streak probably contemporaneous with the more siliceous rocks.

West of this old granite-rhyolite area, andesite comes in above it again, of the same kind as before. Where it has been deeply eroded a coarser textural type is exposed; for example, the hornblende-andesite with cryptocrystalline groundmass, which represents the rocks near the surface, gives way in some deeper cuts to hornblende-andesite with granular groundmass, which is transitional to hornblende-diorite-porphyry.

SEDIMENTARY ROCKS.

TRIASSIC LIMESTONE.

Southeast of Dayton, limestone, in extremely scanty outcrops, just visible beneath the overlying volcanics, was found on both sides of the range. On the eastern side the limestone is massive, dark-blue and sometimes siliceous. Its laminæ are vertical, although they may result more from shearing than from stratification. It is cut by andesite dikes. On the western side of the mountain, in Eldorado Canyon, the limestone is also blue and siliceous, changing to shaly *and carbonaceous*. It is crushed and seamed, but appears nearly

horizontal. The shaly limestone contains nearly obliterated fossils, upon which Mr. T. W. Stanton comments as follows:

> The collection * * * yielded only fragments and impressions of a *Pecten* and a specimen that appears to be part of an *Ammonite*. These are Mesozoic and probably Triassic.

This locality is probably the same as that mentioned by Whitney[a] as having yielded the Triassic fossil *Goniatites lævidorsatus* Hauer.

This Triassic limestone is probably to be correlated with King's Triassic Star Peak limestone.[b]

In the Pine Nut Range the limestone is probably older than the granitic rock which forms the main range, between its two outcrops,

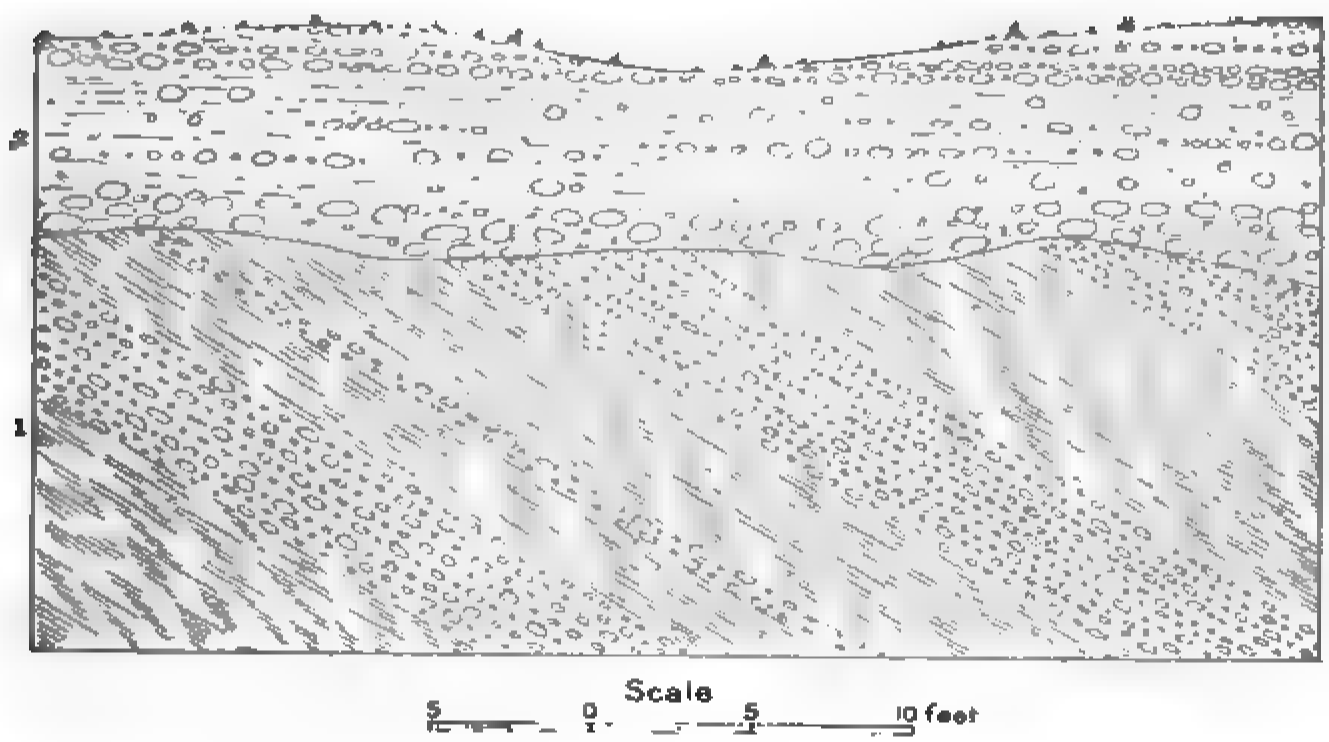

FIG. 9.—Sketch section of wall of arroyo in bottom of Eldorado Canyon, Pine Nut Range.
1. Gravels (pebbles mostly andesite) with coarse clays (Pliocene Shoshone lake sediments?). Tilting probably local.
2. Stratified bowlders and earth (Pleistocene).

for it contains no granitic detritus. The granite must have burst up through the limestone in a great belt.

PLIOCENE DEPOSITS.

On the west flanks of the mountains above Dayton, as already described, there are found some hardened, well-stratified gravels and clays, derived from the andesites, and overlain, often unconformably, by stream gravels (fig. 9). They have the appearance of having been deposited in moving water, but this aspect may well have resulted from current action in a stable water-body. On the face of the range just east of Dayton there is a rough inclined plane running up to a height of 6,000 feet and terminating in obscure benches. Above this termination the mountain rises sharply and steeply, as may be seen on the Carson topographic sheet published by the U. S. Geological

[a] Geol. Surv. California, Vol. I, p. 459.
[b] U. S. Geol. Expl. Fortieth Par., Vol. I, p. [illegible].

Survey. The approximately horizontal upper limit of the plane suggests lake action, and the older gravels and clays in Eldorado Canyon strengthen the idea. At Dayton Professor Russell[a] has placed the limit of one of the bays of Lake Lahontan at an elevation of 4,375 feet. The above-mentioned bench is, therefore, 1,625 feet above the uppermost limit of the Pleistocene lake. Southward from Dayton the leveled plane was not observed, and it is probable that some of the lavas which here form the mountain flanks were laid down in the lake period and so covered the plane or prevented its erosion.

In the plateau valley between Dayton and Carson there occur stratified clays and coarse gravels, at heights of several hundred feet above the Pleistocene Lake Lahontan. Near Carson there occurs a hardened sandstone or granitic arkose, which is well exposed at the State prison. The rock here contains plant remains and occasional fresh-water shells. One of these shells submitted to Dr. W. H. Dall was determined as *Anodonta*, belonging to a recent species found living in California. Dr. Dall adds that the species may be older than the Pleistocene, since the genus goes back as far as the Eocene; but that since the genus is so easily affected by environment, the same species is rarely found in more than two horizons. Excavations in this rock at the State prison have brought to light layers covered with footprints of the extinct elephant and other mammals and birds. On the hill south from the prison there is benching up to a height of 4,850 feet. The same sandstone as shown at the State prison, but somewhat looser and more friable, occurs west of Carson at the foot of the Sierras.[b]

South of this point, along the face of the range, there is a belt of low hills often covered up by the Pleistocene detritus, but consisting, when exposed, of stratified sands and gravels. On the western face of the Pine Nut Range, southward from Carson, there is generally visible a distinct line in the topography at about 6,000 feet, below which the slopes are gentler and above which the mountains are steeper and more rugged. Along the road which crosses the range from Genoa to Wellington stratified sands and gravels, carrying well-rounded pebbles, occur in hills covering the gently inclined plain at

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[a] Mon. U. S. Geol. Survey, Vol. XI, Pl. XLVI.

[b] After writing the above description the writer found that the locality had been already better described by Professor Le Conte and others. He lets his own description stand only to show how independent observations have led to similar conclusions.

Professor Le Conte (On certain remarkable tracks, found in the rocks of Carson quarry: Proc. Cal. Acad. Sci., Aug. 27, 1882) describes a few fresh-water fossil shells of species still living in the vicinity. Among the vertebrate remains are fragments of tusks and molars of an elephant, and molars and fragments of jaws containing molars of two species of horse.

Concerning the age of the beds he concludes that if not Quaternary, they can not be earlier than Upper Pliocene passing into Quaternary. He also suggests that they are possibly deposits of King's Lake Shoshone, and not Lake Lahontan.

Professor Le Conte observed that the level at this locality is 240 feet higher than the uppermost shore line of the Pleistocene Lake Lahontan, which, moreover, did not extend so far west as Carson.

the base of the steeper mountains. These hills are considerably eroded. Near the mountains the pebbles are larger, and in crossing the range the stratified deposit stops at 6,000 feet precisely, above which the rocks are bare. Below the uppermost gravels are benches in the detritus and in the lava on which the detritus lies. These benches, as well as the canyon of the Carson River at this point, seem to have been cut during the recession of the lake to which the gravels owe their origin, and whose uppermost shore line was at the 6,000-foot cut. On the western side of the range there is also a pronounced scarp above the 6,000-foot contour, and beneath this stratified gravels constitute the foundation of the valley between the Pine Nut Range and the northern end of the Sweetwater Range.

The uniform and general distribution of these water-deposited gravels and sands, up to about 6,000 feet, and the horizontal groin which occurs on the mountains about the same height, suggest that the deposits were laid down in a lake, which had its surface at its time of maximum extension at the altitude above mentioned. That the lake was older than the Pleistocene is shown by the fact that the Pleistocene Lake Lahontan reached an altitude of only 4,375 feet. The induration of the sediments of this higher lake, as seen in the sandstone of Carson, also points to a greater age; and the great amount of subsequent erosion, illustrated in the carving of the canyon of Carson River, indicates that the maximum extent of the lake was at a period which was removed from the period of maximum extension of Lake Lahontan by a time interval much longer than from the latter period to the present day. On the whole the deposits of this older lake will be considered late Pliocene.

SWEETWATER RANGE.

The Sweetwater Range may be considered as the southern prolongation of the Pine Nut Range, from which it is separated by the valley of the West Walker River, at Wellington. It is also a spur of the Sierras, into which it passes at its southern end.

TOPOGRAPHY.

The Sweetwater Mountains are high and rugged for the most part, with bold peaks and cliffs. The eastern face of the northern part of the range, from Wellington southward to Desert Creek, is steep and straight. Southwest of Wellington the West Walker River has cut a deep canyon along the face of the range, below the level of the broad desert valley separating it from the Pine Nut Range. On the road from Wellington to Sweetwater, the Sweetwater Range is separated from the Smith Valley Range on the east by the deeply cut Dalzell Canyon.

IGNEOUS ROCKS.

POST-PLIOCENE BASALTIC LAVA.

The gravels and sands which occur in the valley separating the northern end of the Sweetwater Range from the Pine Nut Range belong to the ancient sediments which have already been provisionally classified as Pliocene. Along the canyon of the West Walker River, a short distance southwest of Wellington, there occur in places sheets of columnar basaltic lava, overlying the gravels. This is probably nearly contemporaneous with the basalt in Eldorado Canyon, of the Pine Nut Range.

LATE RHYOLITIC LAVA.

The highest portion of the Sweetwater Range, just west of the post-office at Sweetwater, is distinguished by the brilliant light-gray, yellow, and red which its rocks assume on weathering. These rocks all seem to be gray, essentially fine-grained, thin-bedded surface volcanics. They were not examined in place, but a typical specimen selected from the blocks derived from this mountain proves on chemical analysis to be very siliceous rhyolite[a] or tordrillite.[b]

LATE ANDESITE AND LATITE.

In the same canyon as above mentioned (near Wellington), there occurs, beneath the rolled gravels, stratified ash, dipping northwest away from the mountains. Below this ash occurs lava, through which also the river has cut. There are two distinct flows, the lower of which has a perfect columnar jointing, while the upper one is often brecciated and rests upon the apparently eroded surface of the lower. The rock of the lower flow, microscopically examined, proves to be bronzite-andesite, that of the upper one hornblende-biotite-latite. The uppermost of these flows has been deeply weathered, and has been displaced by a fault, which is subsequent to the weathering.

The andesite is of the same composition as the ancient andesite which forms the greater part of the range, but its association with breccias and gravels stamp it as being younger than the main mass and intermediate between it and the latite.

In Dalzell Canyon are coarse volcanic breccias, with thin inter-banded flows, all dipping at moderate angles irregularly. A specimen from a hard bowlder in the breccia is hornblende-bronzite-andesite. These breccias and thin flows are probably younger than the massive andesite of the main range. They are very likely of about the same

[a] Dr. H. W. Fairbanks (Am. Geol., Vol. XVII, p. 152) mentions a rock in Ferris Canyon, in the Sweetwater Range, which is probably the same as that above described.

[b] Tordrillite is proposed as the fine-grained equivalent of alaskite, and differs from rhyolite in being in general more siliceous and containing no essential ferromagnesian minerals. See J. E. Spurr, Classification of igneous rocks according to composition: Am. Geol., Vol. XXV, 1900, p. 210.

age as the breccias in Eldorado Canyon, in the Pine Nut Range, which they resemble exactly.

Just south of the post-office at Sweetwater similar hornblende-bronzite-andesite comes in, overlying the ancient rhyolite series. This is of the same general age as the breccias in Dalzell Canyon.

EARLIER ANDESITES.

Most of the Sweetwater Range to the north of the high gray rhyolitic peaks above described is of red, deeply eroded lava. Near Wellington, and at the northern end of Desert Creek, specimens of this lava proved on examination to be hornblende-bronzite-andesite.

The main mass of hornblende-pyroxene-andesite forming the bulk of the Sweetwater Range is older than the thin flows and breccias previously described. The later andesites are closely associated with gravels which were chiefly derived from the erosion of the earlier andesite.

EARLIER RHYOLITE.

Just below Sweetwater there outcrops a gray lava which has somewhat the aspect of a pyroclastic breccia. A specimen proves to be rhyolite, with a microcrystalline granular groundmass, and containing small fragments of a gray basic lava free from quartz. This rock is of exactly the same type as one examined from the banded granite-rhyolite series in the Pine Nut Range, on the road between Genoa and Wellington. At Sweetwater, also, this lava has an ancient appearance. It has a pronounced jointing, or sheeting, in two directions, at right angles to one another, one striking N. 70° E. and dipping 70° SE., and the other dipping 70° NE. This rhyolite is overlain by hornblende-bronzite-andesite.

GRANITIC ROCKS.

Along the eastern side of the northern portion of the Sweetwater Range, south of Wellington, there is, back of the main scarp, a second scarp composed of gray and massive rocks. In the bottom of the valley east of here are rolled pebbles and bowlders of granular and porphyritic granitic rocks. As one goes southward from here he may trace the scarp of gray rocks into Desert Creek Canyon, which seems to be cut in similar rocks, and the uppermost portion of Desert Creek Peak is seen to be of the same material. Just east of Desert Creek Peak, at Wileys, granite actually outcrops, beneath hornblende-bronzite-andesite. The granite is in part coarse and porphyritic, containing large feldspars, which have inclusions of dark minerals, and is of the same variety as noted at Belmont, Ellsworth, and on the eastern face of the Pine Nut Range, southeast from Dayton. There is also some nonporphyritic granite, and some containing few dark minerals, and so verging on alaskite.

The granitic rocks have been decomposed to a depth of many feet, so that no specimens could be collected. This decomposition occurred before the eruption of the andesite, for this lava is fresh where it overlies the rotten granite. The period sufficient for this decomposition is considerable, and it must have been preceded by a long period of erosion, which exposed the granite.

In the valley drift above noted there was found, besides granite, specimens of porphyritic siliceous rock, transitional between granite and rhyolite. It is possible that the granite and the rhyolite at Sweetwater may be of nearly the same age and may be correlated with the ancient granite-rhyolite series of the Pine Nut Range.

SEDIMENTARY ROCKS.

PLIOCENE DEPOSITS.

The valley which separates the northern end of the Sweetwater Range from the adjacent Pine Nut Range is covered with bedded gravels, through which West Walker River has cut a Pleistocene canyon. Besides the rolled gravels, which are largely derived from the andesite of the mountains, there are some beds of stratified ash. Across the range from here, the foot of the main scarp north of Desert Creek ends in a sloping plain at an elevation of 6,000 feet; and in the valley below this the deposits consist of rolled gravels similar to those exposed in Walker River Canyon.

South of Dalzell Canyon and east of the highest peaks of the Sweetwater Range is a broad, gently sloping valley, several miles across, reaching back to the Sweetwater Mountains, which rise sharply from it at an altitude of about 7,000 feet. The surface of this valley is smooth, and slight cuts in it show a stratified deposit of arkose and angular fragments of lava.[a]

All these deposits are provisionally referred to the Pliocene.

RÉSUMÉ.

Probably the oldest rocks of the range are a series of granites and ancient rhyolites, which were perhaps contemporaneous. They have been jointed by dynamic action, and are deeply decomposed.

The succeeding geologic formation was a hornblende-pyroxene-andesite, which was poured out in great masses over the underlying siliceous mountain core. Subsequent to this, the andesite was deeply eroded, and probably a lake was formed. The material derived from the erosion of the andesite and of the underlying siliceous rock was spread out in the valleys as gravels.

During this erosion period thin sheets of andesite similar to the main mass were poured out.

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[a] See description of Smith Valley Range, p. 119.

Later than this, but also probably while the lake still existed, a more siliceous lava, which has been classified as hornblende-latite, was poured out in comparatively thin sheets. The rhyolites or tordrillites of the highest portion of the range were probably poured out at approximately the same period, so far as we can judge from the amount of erosion.

The shrinking of the lake exposed to erosion those lavas which had been poured out in it, and the present stream canyons were cut in the lake sediments and the lavas. At the same time thin sheets of basaltic lava were locally erupted.

At the southern end of the Sweetwater Range there appears to have occurred, subsequent to the retreat of the lake, a local uplift, which has elevated the lake sediments and shore lines 1,000 feet above the same sediments in the regions north of here.

VIRGINIA RANGE.

The Virginia Range lies next east of the Sierras and north of Carson. It is separated on the south from the Pine Nut Range by a narrow plateau valley, in which Carson River has cut a Pleistocene canyon. The range rises abruptly from the plains at its base, and is high and rugged. The northern portion was examined by the geologists of the Fortieth Parallel Survey, and the geology of this part is represented on map 5 of the atlas accompanying that report. In the southern part of the range is the famous Comstock lode, and in this vicinity the geology has been studied in detail by King, Becker, and others.

IGNEOUS ROCKS.

With one or two unimportant exceptions, the Virginia Range is made up entirely of igneous rocks. These were thoroughly studied by Dr. Becker,[a] and later were made the subject of a critical study by Messrs. Hague and Iddings.[b]

The igneous rocks consist partly of rocks with porphyritic structure and fine-grained or glassy groundmass, partly of those porphyritic rocks whose groundmass is comparatively coarse, and partly of typical granular rocks. At first these rocks of different structures but similar composition were described as distinct from one another and of different ages, but Hague and Iddings considered that the structures above enumerated occur in the same eruptive bodies, the finer-grained structures having occurred at or near the surface, while the coarsely granular ones are typical of the core of the mountain, now made accessible by the deep mine workings. These conclusions were afterwards contested by Dr. Becker.

[a] Geology of the Comstock lode and the Washoe district: Mon. U. S. Geol. Survey Vol. III. Also California Acad. Sci., Bull. 6, 1886.

[b] On the development of crystallization in the igneous rocks of Washoe, Nevada: Bull. U. S Geol. Survey No. 17.

According to Dr. Becker, the succession of igneous rocks in this district is, beginning with the oldest:

Granite, metamorphics, granular diorites, porphyritic diorites, quartz-porphyry, porphyritic diabase, later diabase (black dike), earlier hornblende-andesite, augite-andesite, later hornblende-andesite, basalt.

The succession, according to Hague and Iddings, is as follows:

1. Pyroxene-hornblende-andesite (in its coarser inner portions becoming pyroxene-hornblende-diorite-porphyry and pyroxene-hornblende-diorite).

   Period of volcanic rest and denudation.
2. Hornblende-mica-andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene-andesite.
6. Basalt.

All these igneous rocks are considered by Hague and Iddings as Tertiary, but they have been divided into Tertiary and pre-Tertiary by Becker and others.

SEDIMENTARY ROCKS.

ANCIENT LIMESTONES.

Mr. Becker[a] described near Virginia a small area of distinctly stratified rocks, consisting of limestones and greatly metamorphosed micaceous schists. No fossils were found. They are perhaps similar to the Triassic limestones found a few miles south of here, in the Pine Nut Range near Dayton. (See p. 207.)

[a] Mon. U. S. Geol. Survey Vol. III, p. 190.

CHAPTER III.

RANGES OF SOUTHERN NEVADA.

VIRGIN RANGE.

The Virgin Range is just within the eastern limit of the folded strata of the Basin ranges and west of the nearly horizontal rocks of the Colorado Plateau.[a] According to Dutton,[b] the exact boundary between these two provinces is the Grand Wash, the valley which lies immediately east of the Virgin Range. In this valley is a heavy fault with downthrow to the west. Dutton says:

> This fault is the boundary of the Grand Canyon district and of the Plateau country itself. The region beyond is a Sierra country, with the same characteristics as the Great Basin of Nevada and western Utah.

SEDIMENTARY ROCKS.

PRE-TERTIARY.

According to Marvine[c] the rocks exposed in the main body of the Virgin Range present the same general sequence as is shown in that portion of the range cut by the Colorado River. The fundamental rocks are Archean gneisses, schists, granites, etc., overlain by Cambrian rocks, which in turn are capped by a great thickness of Carboniferous rocks of the Red Wall and Aubrey groups. At the extreme northern end of the range, east of Beaver Dam Wash, an area of red sandstones, supposed to be Triassic, although no fossils were found, has been mapped by the geologists of the Wheeler Survey,[d] but is not included in the map accompanying the present report.

PLIOCENE.

Besides the Archean and Paleozoic rocks, Marvine[e] describes in the Grand Wash, which lies just east of the Virgin Range, a series of compact conglomerates, which constitute a very large amount of the valley filling and which have often been eroded into a rolling or hilly surface with deep valleys. This conglomerate contains some beds of lava, is horizontally bedded, and abuts unconformably against the folded Carboniferous rocks of the mountains. Southward from the

[a] E. E. Howell, U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 232.
[b] C. E. Dutton, Second Ann. Rept. U. S. Geol. Survey, p. 128.
[c] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 194.
[d] Idem, Atlas, geologic sheet No. 66.
[e] Idem, Vol. III, pp. 197, 198.

Colorado, in another valley, the same gravels or conglomerates are met with, overlain by calcareous tufas several hundred feet in thickness.

On traveling along the west side of the Mormon Range toward the pass between it and the Muddy Range, the writer noted that the greater portion of the valley of the Virgin River lying east of the Virgin Range was covered with slightly eroded Tertiary strata, probably identical with the horizontal red, gray, and brown sandstones and conglomerates observed in the lower portion of the Meadow Valley Wash.[a] The conglomerates in the Grand Wash, on the other side of the Virgin Range, described by Marvine, probably belong to the same series. As observed by the writer in the Meadow Valley Wash, they have the appearance of having been deposited in a lake, although it is possible that they represent the valley accumulation of the Colorado River, at a period when the streams of this system occupied wide valleys, in which they worked laterally and deposited the material which they derived from the erosion of the mountains, the carrying power of the streams at that time not being equal to the amount of load received. These sediments occupy the older valleys which were eroded in the Paleozoic limestones and in the earlier Tertiary sediments and lavas, but they were laid down before the down cutting of the latest sharp gorges, for they stand as the walls of these. They lie against the Carboniferous limestones, and, as described by Marvine, against the Archean granites along the Grand Wash.

According to Dutton[b] the greater part of the general denudation of the Colorado drainage region was probably accomplished in Miocene time, whereas the cutting of the Grand Canyon probably began in the early part of the Pliocene. The conglomerates and sandstones under consideration were evidently deposited just before the period of rapid canyon cutting, and this, in conjunction with the evidence afforded by the underlying unconformable Tertiary rocks in Meadow Valley Canyon, may be sufficient grounds for specifying their age provisionally as Pliocene.

IGNEOUS ROCKS.

Marvine[c] describes large masses of black basaltic lavas resting upon the eastern base of the Virgin Range. Where the Colorado River cuts the range, at Virgin Canyon, Mr. Gilbert[d] describes lavas overlying the gneissic Archean rocks.

STRUCTURE.

As seen from the west, the limestones of the central portion of the Virgin Range present dips of 15° to 30°, and strikes indicating some-

[a] See p. 143.

[b] Second Ann. Rept. U. S. Geol. Survey, p. 67.

[c] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 196.

[d] Ibid., p. 35.

what irregular folding. Marvine[a] records that the main fold of the range is anticlinal and that a fault exists along the east face. This is probably the fault mentioned by Dutton,[b] which has a downthrow to the west of between 6,000 and 7,000 feet.

Toward the south the folding appears to die out so as to be nearly horizontal in the Colorado Canyon.

COLORADO CANYON.

That part of the canyon of the Colorado which is represented in the southeastern corner of the map accompanying this report lies near the boundary between the Colorado Plateau on the east and the region of the Desert or Basin ranges on the west. The Colorado Plateau is characterized by nearly horizontal rocks forming mesas or benched platforms, while the region to the west has many different ranges of high rugged mountains composed of folded strata.

The rocks exposed in this portion of the canyon are Carboniferous and lower. At the mouth of the Grand Canyon Mr. Gilbert made a section showing[c] over 5,600 feet of rocks, being all horizontal strata except the extreme base, where the granites and gneisses of the Archean appear. Above the Archean rocks are 755 feet of shales, sandstones, and some limestone belonging to the Upper Cambrian of the Tonto group. Above the Cambrian comes in, in apparent conformity, heavy limestones with some sandstones, having a thickness of 2,675 feet. This is the Red Wall limestone of the Carboniferous. Above the Red Wall comes in the Aubrey group of the Upper Carboniferous, consisting of 1,300 feet of shales, sandstones, and cherty limestones.

Later, Mr. Walcott[d] found in the Grand Canyon a slight thickness of Devonian, rarely over 100 feet, between the Red Wall limestone and the Tonto rocks. Often the Devonian in this region is entirely absent, either through erosion or nondeposition. The rocks of this period are thin, purplish, fine-grained sandstones, becoming calcareous and containing unmistakable fossils. Mr. Walcott observed an erosion break at the top of the Tonto strata, and another between the Carboniferous and the Devonian. No Silurian rocks are present.

At the base of the Tonto there is a great unconformity, beneath which occur sandstones, shales, limestones, and ancient lavas of the Chuar and Unkar divisions of the Grand Canyon group resting upon thin-bedded quartzites, which stand vertical and are broken through by intrusive masses of granite. Mr. Walcott considers that the strata

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 194, 196.

[b] Second Ann. Rept. U. S. Geol. Survey, p. 126; also Mon. U. S. Geol. Survey Vol. II, atlas Pl. II.

[c] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, fig. 82, p. 196.

[d] Am. Jour. Sci., 3d series, Vol. XXVI, pp. 437, 484.

between the Tonto and the thin-bedded quartzites belong to the Algonkian. The quartzites are Algonkian or Archean.[a]

As one proceeds down the Colorado River from the Grand Canyon, he finds the upper strata successively disappearing, until, in Boulder Canyon and below, the Archean granites, gneisses, and schists come to the top of the canyon, except where covered up by Tertiary lavas.

MORMON RANGE.

The Mormon Range lies immediately east of Meadow Valley. It has an extent of about 40 miles, and a north-northeast trend. At its south end it is divided from the Muddy Range by the valley of Muddy Creek, while at its northern end it merges into irregular volcanic mountains which cover a large area southeast of Pioche.

In topography the Mormon Range is not extraordinary, its peaks being fairly rugged and of moderate height. Running along the central part of the range, and parallel with its axis, is a continuous notch or incipient valley, about 2,000 or 3,000 feet deep, which nevertheless has not yet been deeply enough eroded to form part of the true valley system.

SEDIMENTARY ROCKS.

CARBONIFEROUS.

The great bulk of the Mormon Range is almost free from igneous rocks and is made up of a dark-blue, sometimes crystalline limestone, with some reddish shaly beds. In Meadow Valley Canyon, on the northeast flanks of the range, a spur of this limestone contained the following fossils which were determined by Dr. Girty, of the United States Geological Survey, to be Upper Carboniferous:

Crinoid stems.
Fenestellid.
Fistulipora sp.
Productus nebraskensis.
Productus splendens?.
Productus punctatus?.
Spirifer cameratus.
Spiriferina gonionotus.
Seminula mira.

This is probably the Red Wall limestone group of Gilbert's Grand Canyon section.[b]

The same limestone series is exposed in Hackberry Canyon, a few miles south of here, and it probably constitutes the bulk of the range.

In drift from the southern part of the range, found in the southern part of Meadow Valley, were pebbles containing the following Upper Carboniferous fossils:

Syringopora multattenuata.
Fusulina cylindrica.
Archæocidaris sp.
Chætetes milleporaceus?
Productus semireticulatus.

Below Hackberry Canyon, in Meadow Valley Canyon, there is

[a] Fourteenth Ann. Rept. U. S. Geol. Survey, pp. 505, 506, and 507.
[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 178, 196.

found, overlying the more massive dark-blue limestone, a series of pink sandstones, cherty limestones, and shales of considerable thickness. At Kane Spring, thin-bedded, siliceous, cherty limestones, with yellow, limy shales, belonging to this upper series, contain poorly preserved fossils, referred by Dr. Girty to the Upper Carboniferous. This is undoubtedly the Aubrey group of the Grand Canyon section.[a]

The Aubrey Carboniferous lies conformably on the Red Wall Carboniferous, and both lie conformably beneath the lower rhyolite series of Meadow Valley Canyon.[b] They are separated from the later Tertiary formations, especially the probable Pliocene sandstones and conglomerates, by a marked unconformity.

PLIOCENE.

The Pliocene which lies against the flanks of the Mormon Range, in Meadow Valley Canyon, will be considered in the special description of the canyon. The rocks consist of horizontal or slightly undulating red, gray, and brown sandstones and conglomerates, the latter often honeycombed, rising to a height of about 5,500 feet above sea level, and lying against the folded limestones of the mountains. The conglomerates contain pebbles of the fossiliferous Carboniferous limestones, as well as of the older Tertiary formations.

As seen from the gap between the Mormon Range and the Muddy Range, large areas on the eastern side of the Mormon Range are probably occupied by Pliocene strata similar to those found on the western, these beds covering much of the broad valley between the Mormon Range and the Virgin Range.

IGNEOUS ROCKS.

Despite the fact that much volcanic material was found closely adjacent to the Mormon Range on the north and west, there seems to be little in the range itself. The volcanic rocks on its western flanks will be treated in the description of Meadow Valley Canyon.

STRUCTURE.

The Mormon Range, as viewed from the west, appears to consist chiefly of an anticlinal fold, whose trend diverges somewhat from that of the range, since it runs in a direction west of north, while that of the range runs east of north. On the western slope of the range there was observed a parallel synclinal fold of comparatively small extent, flanked by another slight anticline still farther west. These two folds are probably local. They are succeeded on the west by a syncline which occupies the broad plateau valley in which Meadow Valley Canyon lies. (See fig. 10.)

As seen from the north the main anticline is comparatively gentle,

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[a] Gilbert, U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 177, 196.

[b] See description of Meadow Valley Canyon, p. 140.

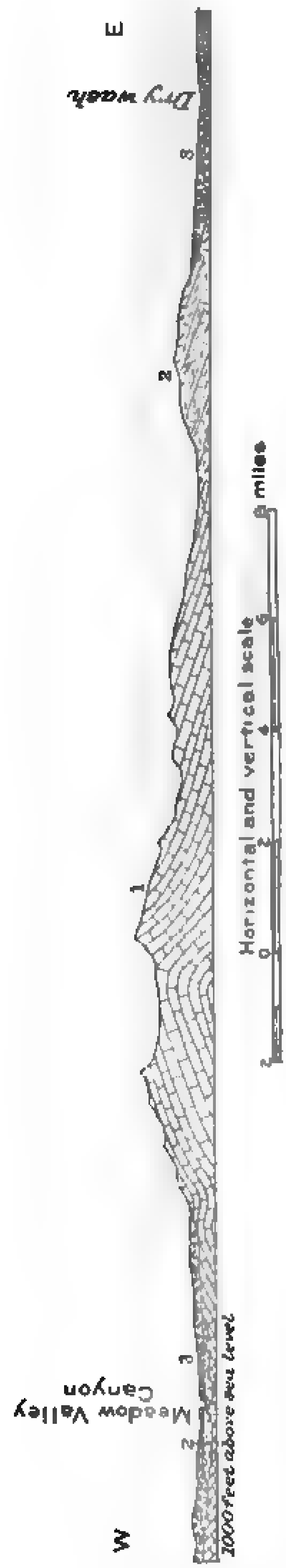

FIG. 10.—Generalized cross section of northern end of Mormon Range.
1 Carboniferous limestone. 2 Chiefly folded siliceous volcanics and derived sediments (early Tertiary). 3 Slightly folded conglomerates and sandstones with lavas (late Tertiary Pleistocene)

the dips on both sides appearing to be about 15°. Farther south, however, these dips gradually increase, and in one conspicuous peak in the south-central part of the range the strata are sharply compressed, forming a type of structure quite unusual in the desert ranges, but still present, especially in certain ranges lying closely east of the Sierra Nevada.[a]

It has already been noted that the limestone which forms the Mormon Range seems to be conformably overlain, on the flanks of the range, by a Tertiary rhyolite and rhyolite tuff series.[b] That there was an erosion interval between the Carboniferous and the rhyolite period is shown by the irregularity of the contact, as, for example, at the mouth of Hackberry Canyon, where the rhyolite is found on one side of the canyon and not on the other. Nevertheless, most of the folding which brought about the formation of the range certainly did not begin until after the rhyolite period. The limestones must also have taken part in later movements, evidenced by folding in the postrhyolitic Tertiary rocks to be described in considering Meadow Valley Canyon, which are separated from the rhyolites by an unconformity. Thus the total amount of folding in the range is the combined result of all the Tertiary movements, which, from phenomena observed in Meadow Valley Canyon, seem to be still in progress.

MUDDY RANGE.

The Muddy Range is a southward continuation of the Mormon Range, being separated from it only by the gap of Muddy Creek. It extends south to the Colorado River, where it is separated from the Colorado Range by Boulder Canyon.

[a] C. D. Walcott: Am. Jour. Sci., 3d series, Vol. XLIX, 1895, p. 169.
[b] See description of Meadow Valley Canyon, p. 140.

SEDIMENTARY ROCKS.

The Carboniferous strata of the Mormon Range appear in the field to be continuous into the northern end of the Muddy Range. The southern portion of the range, however, is represented on the Wheeler survey geologic map as composed of Triassic rocks.[a]

At the extreme southern end of the range, in Boulder Canyon, only the Archean igneous rocks and gneisses are exposed, as described by Mr. Gilbert.[b] These are overlain by Tertiary lavas.

The following observations were made by Mr. R. B. Rowe[c]:

CARBONIFEROUS.

About 4 miles west of Logan, on Muddy Creek, there occurs probably Carboniferous limestone, overlying Mesozoic sandstones and conglomerates. Between Logan and Weiser's ranch, above the Narrows, Paleozoic limestone is again shown, being brought against the Mesozoic by a heavy fault. The Mesozoic also seems to lie conformably upon the limestone on one side of the fault plane.

Fossils collected 3 miles west of Logan post-office by Mr. Rowe were determined by Dr. Girty as rather doubtfully Permian.

MESOZOIC.

At the first locality above-mentioned, 4 miles west of Logan post-office, there are bright-red hills of massive cross-bedded sandstone showing no bedding planes. West of these hills are softer red-clay beds, bluish shale beds, gray conglomerates, and thin limestone beds. Some of the limestone beds contain fossils, regarded by Mr. Rowe as Jurassic. Mr. Rowe's collection was examined by Mr. T. W. Stanton, who referred it possibly to the same horizon as fossils from similar beds in the south part of the Spring Mountain Range. He believes the horizon is not younger than the Triassic and may be as old as the Permian, but as the forms are all new no definite statement can be made.

One of the conglomeratic strata contains considerable petrified wood. From some of the darker shales of the Mesozoic some narrow seams of coal, from one-half to one inch in thickness, have been reported.

At the second locality mentioned above, between Logan and Weiser's ranch, the Mesozoic again appears, lying conformably upon the limestone.[d]

TERTIARY.

On the north side of Muddy Creek, above the old California crossing, are the red, yellow, and bluish deposits of the Tertiary. On the

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Atlas Sheet No. 66.

[b] Idem, Vol. III, p. 35.

[c] Taken from his notebooks after Mr. Rowe's death, by the writer.

[d] This Mesozoic is mapped as Triassic to conform with the Wheeler survey mapping in the southern part of the range. It will be observed, however, that these beds may be, in part at least, the same as those mapped in the Spring Mountain range as Jurassic.

south side, and undoubtedly connected with these, are clay deposits of considerable thickness and extent.

Between Logan and Weiser's ranch red and yellow clays and ancient talus deposits, now hardening into conglomerates, lie unconformably upon the Mesozoic.

IGNEOUS ROCKS.

In the northern part of the range the writer[a] observed volcanic rocks overlying the folded strata. On the Wheeler maps patches of basalt are shown in a similar relation in the southern part of the range, and these extend, as described by Mr. Gilbert, to Boulder Canyon.

STRUCTURE.

At the northern end of the range the stratified rocks seemed from a distance to dip eastward at high angles, but the actual structure was not made out. The folding probably decreases rapidly toward the south.

The following observations were made by Mr. R. B. Rowe:

About 4 miles west of Logan there is probably a fault between the Paleozoic and the Mesozoic. The Mesozoic dips quite sharply to

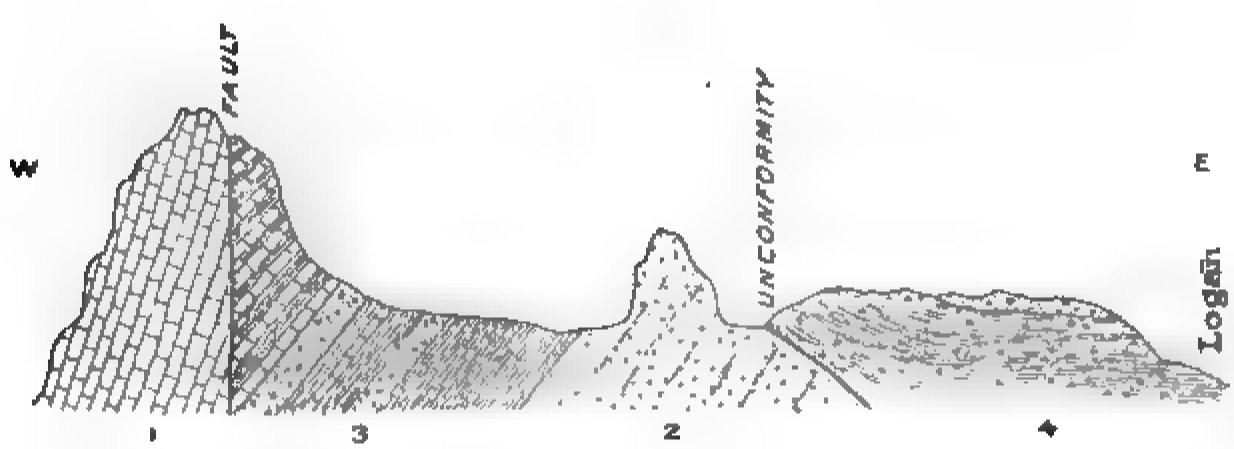


FIG. 11. Cross section of Muddy Range, after R. B. Rowe.

1. Carboniferous limestone.
2. Massive red Mesozoic sandstone.
3. Mesozoic conglomerates, shales, and limestones.
4. Tertiary clays and consolidated talus deposits.

the west. Between Logan and Weiser's ranch the fault is beautifully shown, bringing the Mesozoic against the Paleozoic limestones. On the west side of the range the Mesozoic seems to line conformably upon the limestone. The dip of the limestone is almost perpendicular, while the Mesozoic lies against it, with a much lower dip, on the east side. (See fig. 11.)

COLORADO RANGE.

The Colorado Range is a southward continuation of the Muddy Range, and is separated from it by the Colorado River at Boulder Canyon. Its geology is represented on the Wheeler geologic atlas

a J. E. S.

(sheet No. 66) as consisting essentially of an Archean core overlain by lavas and flanked by Pleistocene detritus.

ELDORADO RANGE.

The Eldorado Range lies west of the Colorado Range, being separated from it by the Colorado River. As represented on the Wheeler atlas, its geology is about the same as that of the Colorado Range.

MEADOW VALLEY CANYON.

TOPOGRAPHY.

Meadow Valley Canyon is cut in the bottom of a broad north-south plateau valley, which separates the Meadow Valley Range on the west from the Mormon Range and other mountains on the east. Although the canyon is dry for long stretches, yet such water as may flow in it is carried to the Colorado, of whose drainage the canyon forms a part. That portion of the valley which is here described is about 90 miles in length, extending from the vicinity of Pioche southward to West Point or Moapa. The canyon begins a short distance south of Pioche, and grows continually deeper toward the south. The continuation of Meadow Valley northward from Pioche is called Duck Valley, which is a typical broad desert valley with no canyon. Opposite Pioche the appearance is already unlike that of the typical desert valley of the region. There comes in a central narrow strip of level wash, marking the channel of drainage, while on both sides there rises to the mountains a detrital slope, which, unlike that of most Nevada valleys, is cut up into low hills. To the south the central drainage channel becomes deeper, the slopes sharper, and the hills more cut up. To the north the reverse is the case, until the valley appears almost flat, like the typical Nevada valley.

From the vicinity of Pioche the incision of the drainage into the valley bottom becomes progressively more pronounced southward, until some few miles south of Panaca a box canyon begins, which soon attains a depth of 500 feet, and, within a few miles, 1,000 or 1,500 feet (Pl. VI, *A*). Some miles south of here, at Kernan's ranch, the canyon walls are estimated to be fully 2,000 feet high. Still farther south, and just northeast of the Mormon Range, the valley widens out into a broad basin inclosed by mountains, for a few miles below which another shorter and somewhat lower canyon is entered. Below this is a broad, gently sloping plateau-valley, in which the drainage channel, though generally sharp, is shallow. This plateau grows wider toward the south, as also the valley which is cut in it. At the junction of the Muddy Creek and Meadow Creek drainage, near West Point or Moapa, the valley is 2 miles wide.

Meadow Valley Canyon offers exceptional advantages for study. Most of the Nevada deserts are nearly level, and appear to be filled with Pleistocene accumulations, mostly subaerial. Observations in

some of these flat valleys, however, show that Tertiary rocks crop out in patches and that the Pleistocene cover is only a veneer. But, there being no drainage in these valleys, there is very rarely an opportunity to find sections cut by running waters, so as to study the real valley filling. In Meadow Creek Canyon we have such an opportunity. The slight incision in the valley opposite Pioche grows to a continuous canyon 1,000 or 2,000 feet deep, whose walls afford excellent sections of the Tertiary sediments and lavas which constitute the real valley filling between the ranges of Paleozoic strata on either side.

PALEOZOIC ROCKS.

On the west of the valley, the Highland and Meadow Valley ranges, and on the east the Mormon Range, are composed of Paleozoic strata, the Highland Range being chiefly Cambrian, the rest largely Carboniferous. Between these mountain ranges the valley probably existed before the deposition of any of the Tertiary rocks.

RHYOLITE.

The oldest of the post-Paleozoic rocks noted in Meadow Valley Canyon was rhyolite. This was first encountered at the upper end of the canyon, near Yokum's ranch, where it occurs in rugged outcrops. A specimen proved to be a siliceous biotite-rhyolite. This has been eroded, and against it has been laid down a horizontally stratified white rhyolite sandstone derived from it. The sandstone is hardened and forms cliffs and buttes. The rhyolite is thoroughly decomposed.

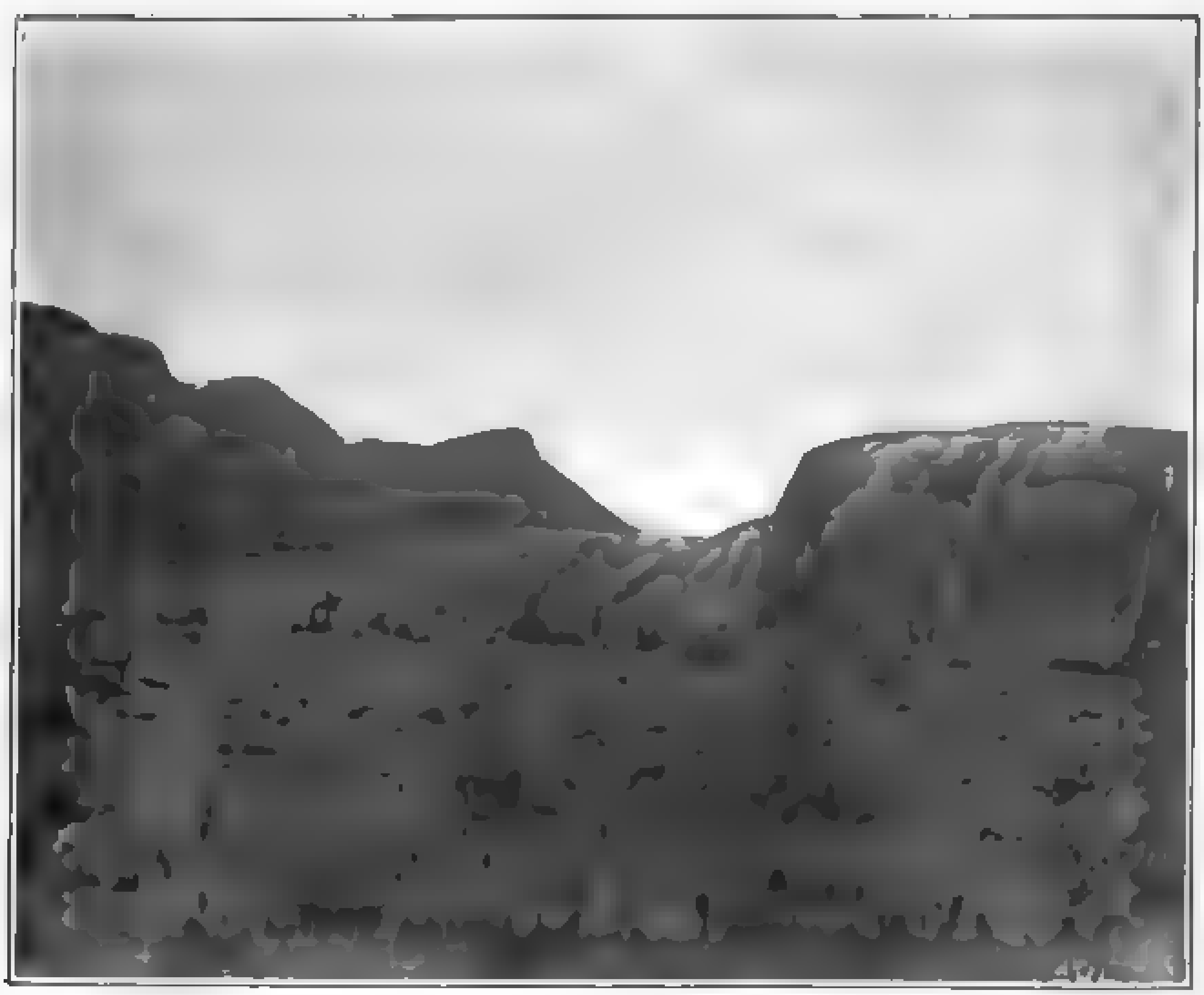
South of here, the basal rhyolite may be traced for some short distance in the canyon walls till it sinks below the bottom of the canyon and gives place to an enormous series of the overlying rhyolite sandstones, which contain interbedded thin sheets of rhyolite. There are in many places evidences that the basal rhyolite was eroded before the deposition of the overlying detrital series, for the latter often rests in the irregularities of the surface offered by the former. The rhyolites and the overlying derived sediments are folded throughout (dipping exceptionally as much as 30°, though usually deviating only slightly from the horizontal), and are often faulted, small faults being numerous, and those of 100 feet or more being not infrequent.

The basal massive rhyolite was again observed at Hackberry Canyon. In the section afforded here the lowest member is a white biotite-rhyolite, thoroughly decomposed. At the mouth of the canyon this rhyolite overlies the Carboniferous limestones conformably, the whole being folded together and unconformable to the overlying formations.

RHYOLITE-SANDSTONE SERIES.

At the upper end of Meadow Valley Canyon, at Yokum's, the consolidated rhyolite sandstone and conglomerate which overlies the massive rhyolite has already been described, and also its occurrence in the canyon immediately to the south, where it succeeds the basal

A. RHYOLITE WALLS OF MEADOW VALLEY CANYON AT CARSON'S RANCH



B. PLIOCENE CONGLOMERATE IN MEADOW VALLEY CANYON AT CANE SPRING.

lava above an apparent erosion gap and is folded with it. The rhyolite-sandstone or tuff series is overlain unconformably by andesite, and is also cut by thin intrusive sheets of it.

There appears also to have been considerable disturbance even during the deposition of the rhyolite-sandstone or tuff series, which is expressed by slight erosion gaps and irregularities between adjoining beds. During the deposition of this series, therefore, periodic effusion of thin sheets of lava and erosion seem to have gone on simultaneously. Some of the thin rhyolite sheets rest one upon another with diverging angles of banding, indicating to the observer

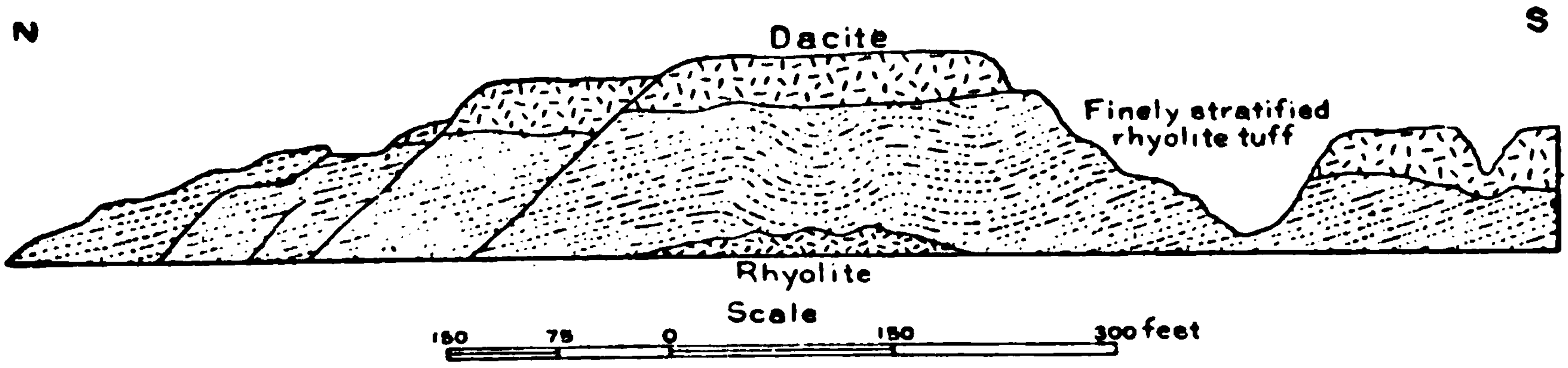


FIG. 12.—Sketch section of east wall of Meadow Valley Canyon just south of Carson's ranch, showing unconformity between rhyolite sands and overlying dacitic lavas.

at first sight an unconformity, since they have the appearance of being white stratified rock.

This series was estimated to be 4,000 feet thick, and is exposed southward to a point about 45 miles south of Pioche, where it gives place, on account of the general southerly dip of the folded beds, to later overlying sediments and lavas.

ANDESITE-LATITE SERIES.

There is found, overlying the rhyolite-sandstone or tuff series, at Yokum's ranch and in the canyon to the south, several hundred feet of basic lava, specimens which proved to be in general bronzite-biotite-andesite. A specimen collected just above Yokum's, probably from the same general series, is biotite-hornblende-quartz-latite.

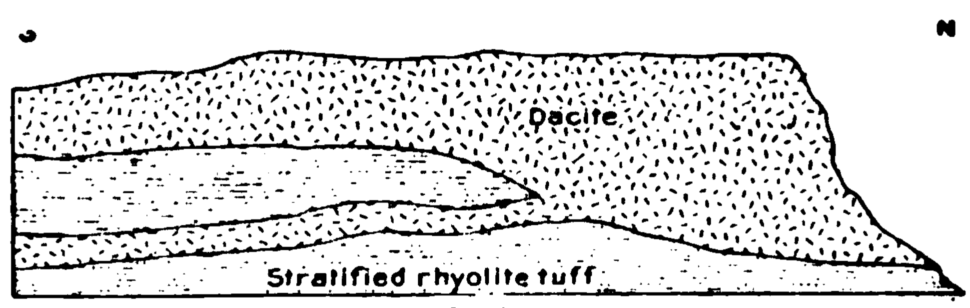


FIG. 13.—Sketch section of west wall of Meadow Valley Canyon at same locality as fig. 12, showing intrusion of overlying sheet of dacitic lava into underlying rhyolite sands.

This andesite-latite series rests unconformably upon the basal rhyolite or on the overlying rhyolite tuff (fig. 12) and also intrudes them in thin intercalated sills (fig. 13).

From the northern end of the canyon the andesites were not observed for many miles southward, but in Hackberry Canyon they were again found exposed in exceptionally good section. Here they overlie the basal rhyolite unconformably, and are themselves tilted so as to be unconformable below the overlying sands and gravels. At

this point, as also at the northern end of Meadow Valley Canyon, the andesite contains considerable masses of volcanic breccia. It is considerably decomposed, though not so much as the underlying rhyolite, and specimens proved to be pyroxene-andesite.

REDDISH DACITES AND RHYOLITES AND ASSOCIATED SEDIMENTS.

In the southern half of the northern portion of Meadow Valley Canyon, above the open basin to the northeast of the Mormon Range, the andesites were not observed; but the rhyolite sandstone or tuff formation was found to be overlain by beds of brown and yellow tuff, containing a variable amount of red lava, in the form of sheets. The great variability in thickness of the lava sheets, and, therefore, of the interbedded sandstones, makes a study of the series very difficult, no two sides of the canyon ever matching; but, so far as examined, the

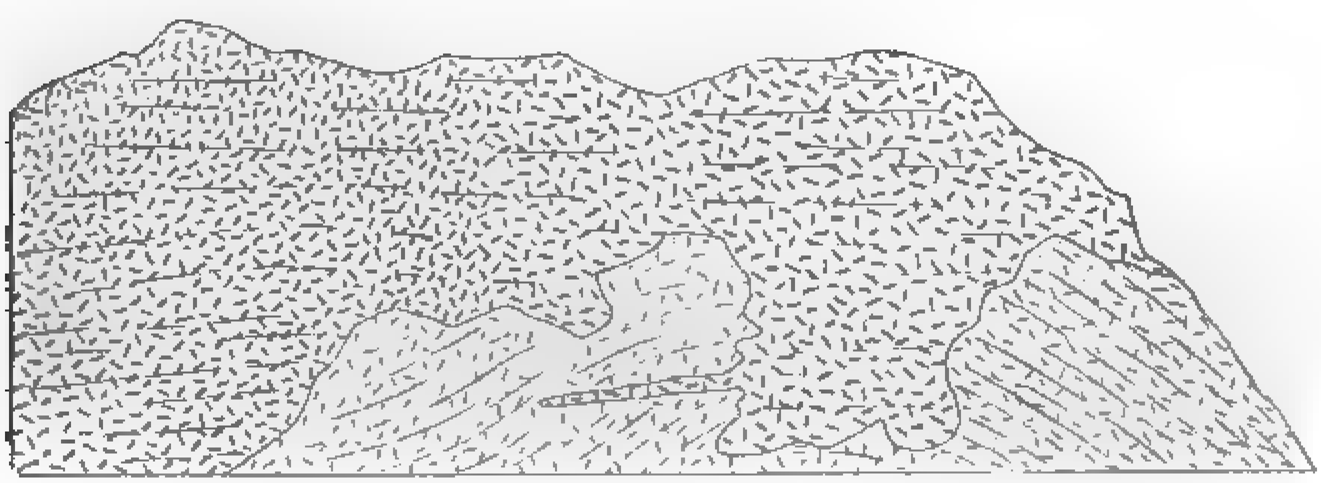


FIG. 14.—Sketch of east side of Meadow Valley Canyon near locality of figs. 12 and 13, showing contact of underlying rhyolite and overlying dacite, with no rhyolite sands between.

volcanic rocks found in this upper reddish series are in part biotite-hornblende-dacite and in part pink rhyolite. It is not plain in the field whether this series of dacites and reddish rhyolites is older or younger than the andesites, for the two are not found together; but from the fact that the andesite is often found resting directly upon the basal rhyolite, it is inferred that it is probably older than the reddish dacite-rhyolite series. Between the series of red lavas and yellow-brown tuffs and the underlying series of white rhyolites and white tuffs there is a marked unconformity and erosion gap (fig. 14).

The dacites and reddish rhyolites not only form interbedded sheets contemporaneous with the yellow-brown tuffs, and furnish many of the pebbles in the associated gravels, but they have cut the same gravels and tuffs as intrusive sills, which are often of considerable thickness. Thus there are exposed sections in the canyon walls with the reddish volcanics at the base and the yellow-brown tuffs above, giving a false appearance, as if the sediments were younger than the lava.

At one locality, near Kernan's ranch, the brown tuffs and red lavas were seen to be overlain by a flow of pyroxene-olivine-basalt, whose lower boundary is irregular.

This whole series of red lavas and brown tuffs is broadly folded, although not so much as the rhyolitic series below. It has in general a southerly dip, and where the canyon gives way below Kernan's ranch to the broad, level basin which lies northeast of the Mormon Range it is overlain unconformably by horizontal brown sandstone or tuff belonging to a later epoch.

PLIOCENE BEDS.

In the valley near Panaca the stream bottom has on both sides scarps 60 to 100 feet high, consisting of horizontally stratified silt and sand. These sediments are sometimes green and yellow and pass into rhyolitic arkose. The scarps are cut down in a level valley plateau which has an elevation of about 5,000 feet; and from here on both sides a succession of benches, more or less dissected, rise to the mountains. The highest well-marked bench was estimated at 6,000 feet.

In the northern portion of Meadow Valley Canyon, between Carson's and Kernan's ranches, the different series of interbedded lavas and tuffs above described, which are all more or less folded, give way for a few miles on the west side of the valley to a deposit of about 2,000 feet of clean, brown volcanic sandstone and tuff, beautifully stratified horizontally, and extending to the top of the hills. The deposits are unfolded and unbroken, dipping south about 2°, and having a maximum elevation of about 5,500 feet. In the upper part of this sandstone series there seems to be a few sheets of rhyolite and basalt, the basalt being the younger.

South of Kernan's ranch a series of brown, horizontally stratified, volcanic sandstones or tuffs comes in uncomformably above the slightly folded red lava and brown tuff series, and fills the broad basin which lies northeast of the Mormon Range. Of these horizontal sandstones there is shown in the bottom of the valley a thickness of about 800 or 900 feet, although neither the bottom nor the top was seen. Below the sandstones are barely exposed horizontal conglomerates, well indurated, and containing pebbles of various sizes up to 2 feet in diameter. This sandstone series continues south, and lies up against the slopes of the Mormon Range to a height of about 2,000 feet above the valley or about 5,500 feet above sea level. The lower portions of the sandstone are indurated, while the upper parts are softer. They are often honeycombed in consequence of unequal consolidation and erosion. In one locality they are overlain by a sheet of very recent tordrillite. These horizontal rocks acquire a slight wavy structure on approaching the spur of Paleozoic limestones which constitutes the southern barrier of the basin. There are developed gentle folds with axes parallel to the spur, and dips averaging not more than 10°.

Close up to the limestone buttress the folding is somewhat closer, and the strata have a wrinkled appearance.

At Hackberry Canyon the same series of horizontally stratified conglomerates and soft sandstones overlies the pyroxene-andesite, from

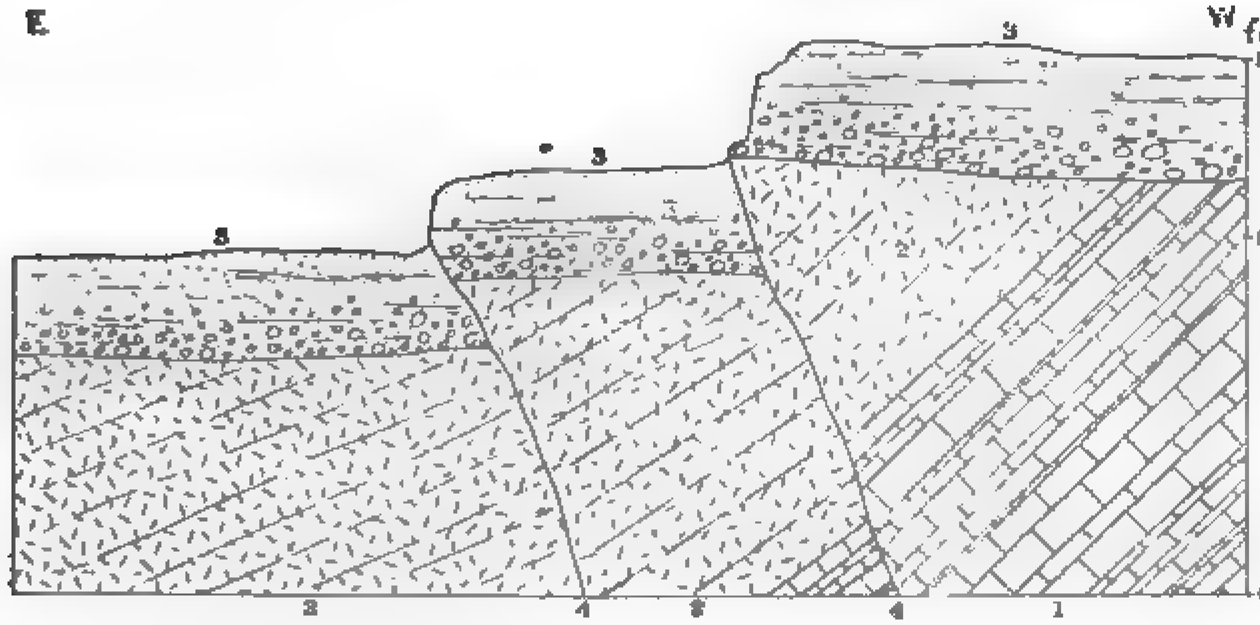


FIG. 15.—Sketch section of south wall of Hackberry Canyon near junction with Meadow Valley Canyon, showing Pleistocene faults and simple fault scarps.

1. Carboniferous limestone
2. Rhyolite and derived sediments (probably early Tertiary)
3. Consolidated honeycombed conglomerate and sandstone (probably Pliocene)
4. Pleistocene faults.

which it is separated by an unconformity and an erosion gap. At the mouth of Hackberry Canyon the same series is found, honeycombed and overlying unconformably the upturned basal rhyolites. Both the horizontal conglomerates and sandstones and the underlying rocks

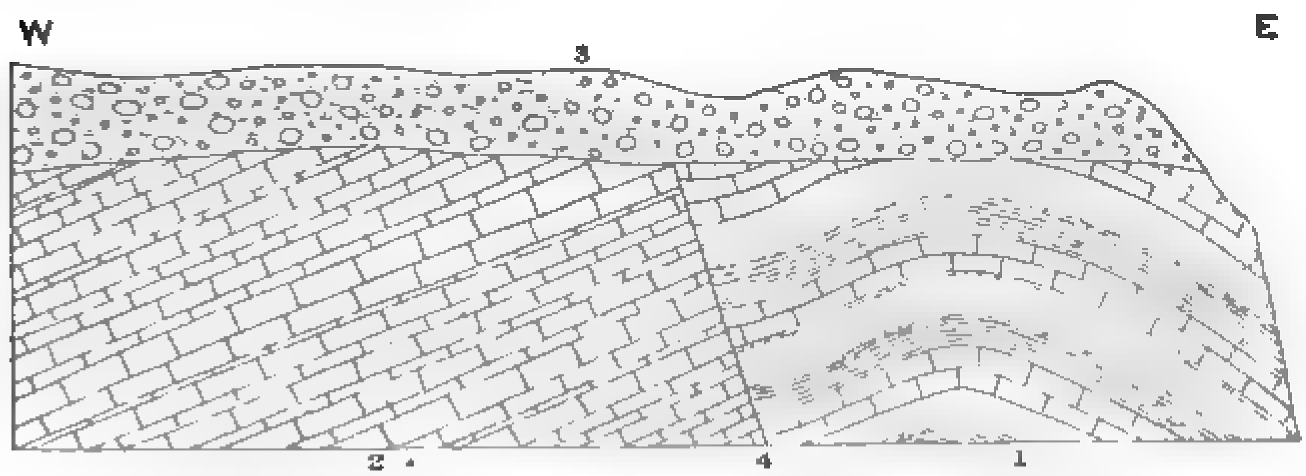


FIG. 16.—Sketch section of north wall of Meadow Valley Canyon, 3 miles southwest of mouth of Hackberry Canyon, showing a pre-Pliocene fault

1. Interbedded pink and yellow sandstones, sandstone shales, and bluish-green siliceous limestones.
2. Homogeneous thin-bedded siliceous limestones (Carboniferous).
3. Pliocene (?) conglomerate.
4. Pre-Pliocene fault

have been displaced by recent faults, which are directly expressed in the topography (fig. 15). Farther south, a short distance down the main Meadow Valley Canyon (or, as it is called at this point, Mormon Canyon), the horizontal conglomerate overlies unconformably the

Paleozoic limestones and sandstones. At this point a fault has displaced the Paleozoic rocks, but not the overlying conglomerates, showing that it occurred before the deposition of the latter (fig. 16). A short distance south of here the horizontal sandstone is brought to the bottom of the canyon by the dipping down of the contact between it and the lower formations, and from here to the neighborhood of Moapa or West Point it is the principal formation exposed in the valley, the older Tertiary deposits not being observed and the Paleozoic rocks only in patches.

From Kane Spring southward to Grapevine Spring, a distance of about 3 miles, there is a very interesting section (fig. 17). Above the upturned and eroded Paleozoic limestones occur the consolidated brownish sandstones, grits, and conglomerates of the horizontal series. The conglomerates contain pebbles of limestone, chert, and quartz from the Paleozoic series, white rhyolite from the basal rhyolite series, and characteristic red lava from the dacite-rhyolite series (Pl. VI, *B*). There has been a slight local folding of the brown sandstones and conglomerates, which seems to have been partly caused by the advent of a considerable sheet of rhyolite. This rhyolite overlies the sandstones and has also cut into them as sills. Probably, however, part of the folding took place before the intrusion. At Grapevine Spring there has been a late faulting which has displaced the lava as well as the sandstones, and here also the upturning of the strata has been

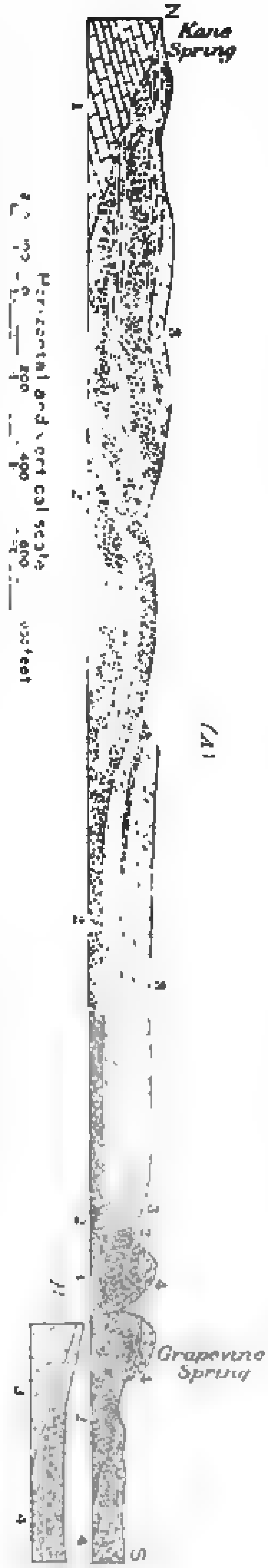


FIG. 17.—*A*, Sketch section on east wall of Meadow Valley Canyon from Kane Spring to Grapevine Spring. *B*, Section on west side of canyon at Grapevine Spring.
1. Upper Carboniferous (Aubrey) limestone.
2. Brownish and reddish sandstones, grits, and conglomerates, semi-consolidated (Pliocene).
3. Glassy rhyolite (Pliocene).
4. Gray sandstones, grits, and conglomerates, semi-consolidated (Pliocene).

greatest, resulting in a local dip of as much as 45°. Lying upon the upturned edges of the brown sandstones here, and also upon the later rhyolite, is a series of consolidated grits and conglomerates, distinguished by a gray color as opposed to the reddish and brown colors of the beds below (fig. 18). Southward from Grapevine Spring to Moapa, the horizontal gray sandstone and conglomerate is continually observed overlying the red and yellow series, which is again horizontal and mostly conformable to it.

The very slight folding of all the beds which have been described under the last head separates them from all the underlying unconformable Tertiary series. Their position, structure, and distribution show that they are probably lake beds, and, indeed, they lie, partly

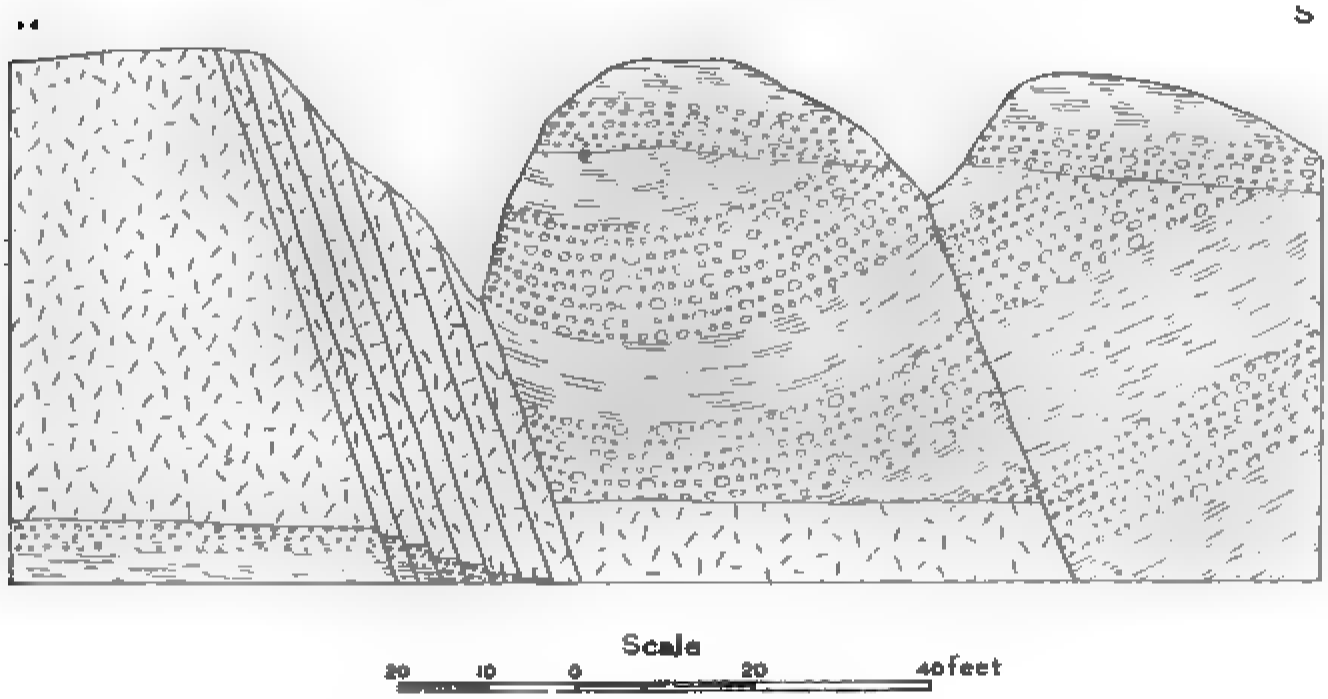


FIG. 18.—Sketch section of west wall of Meadow Valley Canyon at Grapevine Spring. Enlarged from fig. 17. Showing fault gullies in Pliocene rocks.

at least, in inclosed rock basins. These beds are provisionally referred to the Pliocene.[a]

PLIOCENE RHYOLITES.

In the section between Kane Spring and Grapevine Spring the moderately thick sheet of rhyolite above noted is of an age intermediate between the lower brown Pliocene sandstone series and the upper gray Pliocene series, since it overlies the one and underlies the other. It is a glassy rock, and very little can be told of its composition.

PLEISTOCENE RHYOLITE AND BASALT.

At several points very recent lavas are seen, which form the latest phase of volcanic activity in this region. In the canyon near the northern end of the broad basin which lies northeast of the Mormon Range the topmost rock at one point was found to be a sheet of

[a] See description of Virgin and Mormon ranges, pp. [illegible] and [illegible].

pyroxene-olivine-basalt, overlying with an irregular contact stratified volcanic sand apparently belonging to the dacite-red rhyolite period.

Near the southern end of the same basin a thin sheet of glassy tordrillite comes down into the valley, covering the hills in such a way as to show that the present topography was developed before the lava effusion.

At Hackberry Canyon thin sheets of glassy lava overlie the horizontal Pliocene sandstones and conglomerates. Specimens of these sheets, taken at different but neighboring points, proved to be tordrillite and pyroxene-olivine-basalt. The two seem to be practically contemporaneous, and both must be regarded, from their position and

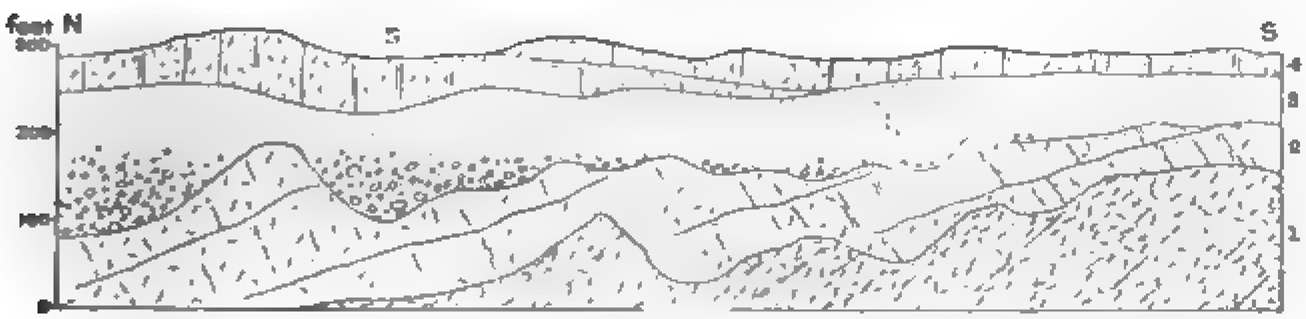


FIG. 19.—Sketch section of wall of Hackberry Canyon at Hackberry Spring.

1. White decomposed rhyolite.
2. Pyroxene-andesite.
3. Conglomerate and soft sandstone (Pliocene?).
4. Thin-bedded, slaggy olivine-basalt (Pleistocene).
5. Thin-bedded slaggy tordrillite (siliceous rhyolite) (Pleistocene.)

their relation to the underlying rocks and to the topography, as Pleistocene (fig. 19).

PLEISTOCENE GRAVELS.

Through all the rocks previously described, except part of the Pleistocene rhyolites and basalts, the drainage has cut a canyon in places as much as 2,000 feet deep. The detritus removed by this cutting has chiefly been carried down the valley and out to the Colorado River, but a certain portion still floors the valley bottom.

SEQUENCE OF EVENTS.

Out of the complicated conditions observed at so many points in the valley of Meadow Creek, the following rough sequence of events may be provisionally laid down:

1. Deposition of the Paleozoic series of quartzites and limestones.
2. Elevation of this series to a land mass and the erosion of the rocks to produce a system of mountains and valleys. This was attended by little or no folding.
3. Pouring out of great masses of white biotite-rhyolite (early Tertiary.)
4. The formation of a series of water-laid rhyolitic sandstones and

tuffs, interbedded with thin sheets of rhyolite and rhyolite breccias. This whole series is roughly estimated at 4,000 feet thick and at the top contains relatively more tuffs, while at the bottom there are relatively more lavas. Several slight unconformities and many slight erosion gaps occur in the series.

5. Folding to a considerable degree of the whole crust.

6. Explosive eruptions of pyroxene-andesites and latites of moderate extent.

7. The formation of a series of water-laid brown volcanic tuffs or sandstones and breccias, with interbedded quartz-bearing volcanics, chiefly dacites and reddish rhyolites. The sandstones were relatively thick at the bottom of the series, the volcanics at the top. The entire thickness of the series is estimated at 3,500 feet. There are some petty erosion intervals.

8. General folding, comparatively gentle.

9. Deposition of at least 2,000 feet of brown or red conglomerates and soft sandstones, which are accompanied by very few volcanic flows and so are distinct from the preceding formations. They have remained nearly horizontal and are probably, in large part at least, lake beds. They have been referred to the Pliocene.

10. Drainage of the Pliocene lake, erosion and slight local folding in the Pleistocene.

11. Outpouring of thin sheets of rhyolite, tordrillite, and pyroxene-olivine-basalt.

12. The formation of a small amount of high stream gravels.

13. Cutting down of the canyon bed to its present position.

The thickness of the basal rhyolite is not known. A very roughly estimated section of the overlying formations is as follows:

Section in Meadow Valley Canyon.

	Feet.
Rhyolite tuff series	4,000
Andesite	600
Red lava and sandstone	3,500
Pliocene sandstones and conglomerates	2,500
Total	10,600

The succession of lavas, so far as can be made out in this confused section, is as follows: Biotite-rhyolite, pyroxene-andesite, biotite-hornblende-quartz-latite, biotite-hornblende-dacite, quartz-latite or red rhyolite and tordrillite, pyroxene-olivine-basalt, glassy rhyolite or tordrillite.

MEADOW VALLEY RANGE.

The Meadow Valley Range lies opposite the Mormon Range, on the west side of Meadow Valley. It is comparatively low and irregular. At the north end it passes into the Highland Range and at the south

into Las Vegas Range, with which it forms a V. Near this point it becomes broader and divides into several parallel petty ridges.

SEDIMENTARY ROCKS.

The Meadow Valley Range is composed chiefly of stratified rocks.

CAMBRIAN.

The mining camp of Delamar is situated on the western slope of the Meadow Valley Range. According to Mr. Emmons[a] the range here consists of limestones underlain by heavy quartzites, these formations corresponding to the Cambrian quartzites and the limestones. There is a belt of shale, as at Pioche. These rocks are continuous northward into the Highland Range, but on the east are overlain by later volcanics.

CARBONIFEROUS.

Along the road which crosses the range from Moapa toward Pahranagat Valley an excellent section is obtained. The rocks are Paleozoic limestones and form two synclinal ridges, with an interior anticlinal valley between. The eastern part of the section consists of rather thin-bedded limestone, full of chert nodules. These apparently overlie the strata of the westernmost ridge, which are dark-blue, semicrystalline limestones, also full of chert nodules, and containing some quartz veins. This is often fetid, and is more massive and of older appearance than the other limestones of the section.

Where the road cuts through the low eastern ridge the following Upper Carboniferous fossils were found, as determined by Dr. Girty:

Fusulina cylindrica.
Archæocidaris sp.
Productus prattenianus.
Productus semireticulatus.

From the apparently lower rocks of the western ridge the following fossils were collected (also Upper Carboniferous):

Zaphrentis sp.
Productus? sp.
Spirifer sp.
Seminula sp.
Macrocheilina? sp.

Between the western ridge and the eastern face of the New Mountains to the west, which are an important branch of Las Vegas Range, a low ridge runs along the middle of the valley, joining the more massive mountains on the south at the angle of the V. This ridge

[a] Oral communication.

is composed of fetid thin-bedded limestones, like those just described. The following fossils were found by Dr. Girty to be Upper Carboniferous:

Fusulina cylindrica.
Syringopora multattenuata.
Productus semireticulatus.
Productus prattenianus.
Pleurotomaria sp.

PLIOCENE.

The Pliocene of the southern portion of Meadow Valley[a] extends westward and forms the flanks of the Meadow Valley Range, abutting unconformably against the upturned Paleozoic limestones. The rocks consist of horizontal red and white sandstones and occasional conglomerates, varied a short distance east of Moapa by a white consolidated volcanic ash. The Pliocene strata occupy a broad belt running north and south. They are locally slightly folded, dipping as much as 10°, but in general are horizontal.

On the western side of the range, in the bay between it and the New Mountains and Las Vegas Range, the same Pliocene sandstones occur.

Some distance north from Moapa and just northwest from Hackberry Spring, as seen from Meadow Valley, the Pliocene deposits seem to rise along the flanks of the Paleozoic Range until they occupy broad areas covering the limestones on the summits of the range, they themselves being capped by volcanics.

IGNEOUS ROCKS.

In the northern half of the range a great part of the rocks exposed at the surface seem to be volcanics, undoubtedly belonging to the Tertiary and Pleistocene flows already described in Meadow Valley Canyon. They probably are associated with Tertiary sediments derived from them, like the beds in the locality mentioned.

STRUCTURE.

The northern end of the range seems to be chiefly volcanic, from which the underlying Paleozoics emerge in places. South of here appear volcanics and associated Tertiary sediments, and the main ridge in the whole southern part of the range consists of folded Paleozoic limestones. The structure in the Paleozoic limestones consists of open parallel anticlines and synclines, generally of no great width or depth. North of the valley of the Muddy the central ridge is synclinal, with an anticline closely adjacent to it on the eastern flanks of the ridge. Irregularities in the erosion sometimes bring this anti-

[a] See descriptions of Meadow Valley Canyon, Mormon Range, and Virgin Range, pp. 131, 135, 143.

cline to the crest of the ridge, as shown in a section observed northwest of Kane Spring. Just west of Grapevine Spring, however, the syncline forms the summit.

South of Muddy Valley, on the road which runs westward from Moapa, the broadening and dividing range shows two principal synclinal ridges with an intervening nonpersistent anticlinal valley. The syncline of the westernmost of these ridges appears to be continuous with the main synclinal ridge farther north. Besides these main folds several petty ones were observed to the east of the easternmost large syncline, consisting of slight alternating anticlines and synclines. In the whole section no less than six adjacent open folds were observed, the synclines generally forming ridges, the anticlines depressions. West of the westernmost syncline, a low Carboniferous ridge in the valley has a westerly dip, and in the depression between it and the synclinal ridge is an anticline, as is shown in the mountains which terminate the depression between the two ridges a few miles farther south (fig. 20).

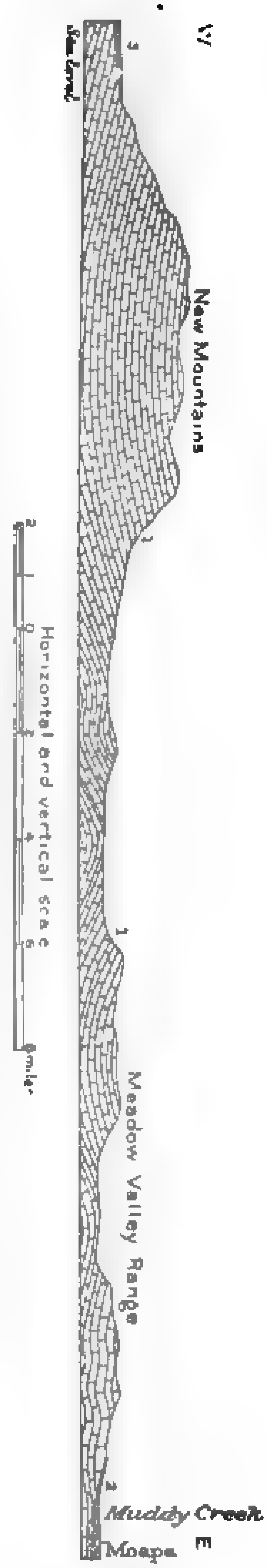


FIG. 20.—Sketch section of southern end of Meadow Valley Range, extended through the New Mountain Ridge.
1. Chiefly Carboniferous limestone. 2. Pliocene (?) horizontal red and white sandstones. 3. Pleistocene valley wash.

PAHROC RANGE.

The Pahroc is a comparatively short range of no great height, lying immediately west of the Highland Range and having a due north-south trend. Its length is not over 25 miles and its width not more than 5 or 6 miles. Only the northern part of the range was seen by the writer, and that from a distance of several miles.

IGNEOUS ROCKS.

Mr. Gilbert[a] reports that the Pahroc Range, on the road from Hiko to Pioche, is of lava, which extends a number of miles north and south.

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 123.

SEDIMENTARY ROCKS.

As seen from the north, the northern end of the range is made up of stratified rocks of moderately thick bedding, evidently limestones. These rocks extend for some distance farther south. Judging from the rocks found just north of here, in the low hills which have been described as forming the connection between the Pahroc Range and the southern end of the Egan Range a short distance northwest of Pioche,[a] the rocks of the Pahroc Range thus exposed are perhaps, in part at least, Devonian. The Silurian may possibly be represented.

STRUCTURE.

The limestones which constitute the northern end of the range seem, when viewed from a distance, to be bent into a single, regular, anticlinal fold, which strikes parallel to the north-south trend of the range. The summit of the range appears to comprise the axis of the fold, and from this the rocks dip on both sides at a gentle angle, averaging about 15°.

HIKO RANGE.

The Hiko Range lies next southwest of the Pahroc Range, with which it is joined at several points by low connecting hills. It has a north-south extent of about 30 miles, and, like the Pahroc Range, its general trend hardly diverges from a due north-south line. On the west the Hiko Range is connected by a series of hills with the Pahranagat Range, and this series of hills continued farther west connects these ranges with the Timpahute Range and the Worthington Mountains. Like the Pahroc Range, the Hiko Range is comparatively low.

SEDIMENTARY ROCKS.

Most of the Hiko Range is composed of limestone of Silurian and Devonian ages. Mr. Gilbert[b] first described Silurian fossils from Fossil Butte, just west of the main range. Subsequently Mr. Walcott[c] made an investigation of the paleontology here, and described many species of fossils. According to Mr. Walcott there is exposed in Fossil Butte the Pogonip limestone of the Eureka series, overlain by the Eureka quartzite. Near Hiko he found shaly limestone, overlain by arenaceous limestone carrying a Devonian fauna.

IGNEOUS ROCKS.

According to Mr. Gilbert,[d] there are a few small bodies of lava in the range.

[a] See description of Egan Range, p. 49.
[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 181.
[c] Mon. U. S. Geol. Survey Vol. XX, p. 195.
[d] Op. cit., p. 123.

STRUCTURE.

Mr. Gilbert[a] found in the Hiko Range north of Fossil Butte westerly dip, but south of this point an easterly dip. There ha been no folding, and therefore there is a scissors fault[b] transvers to the range at about this point. This same peculiar structur feature, according to Mr. Gilbert, is characteristic of all the ridg west of here as far as the Timpahute Range.

PAHRANAGAT RANGE.

The Pahranagat Range lies next southwest of the Hiko Rang with which it is connected at its northern end by Fossil Butte. Fro here it extends southward in a general south-southeasterly directio for about 40 miles, where it is separated from the Arrow Canyo Mountains by a comparatively short transverse stretch of dese valley. The highest mountain in the range is Quartz Peak, at i northern end.

SEDIMENTARY ROCKS.

Mr. Gilbert[c] found Silurian fossils in the northern end of th range. Mr. Walcott[d] found on the eastern side of the Pahranaga Range limestones which he regarded as possibly belonging to th Lone Mountain series of the Silurian. In Quartz Peak, just west o here, he found a fine exposure of Silurian strata comprising the fo lowing divisions:

Section at Quartz Peak.

	Fe
Lone Mountain Niagara	5
Lone Mountain Trenton	5
Eureka	4
Pogonip	7
Total	2,2

South of Quartz Peak he found a great thickness of limeston nearly 8,000 feet in all, broken only by thin beds of yellow sandston the heaviest not over 100 feet in thickness. In this great thicknes of limestone he found no lithologic variation sufficient to bas divisions upon. From the fossils contained he found that the lim stone ranged from Carboniferous through the Devonian into th Silurian. It was impossible to draw any line of demarcatio

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 39.

[b] The writer has employed this term thinking that it was already in use. Mr. Gilbert, ho ever, who has examined the manuscript, believes that the term is original here, and it is the fore defined as a fault whose movement is like that of a pair of scissors when opened, there bei on the fault plane an axis where the differential movement is nothing, while on one side of th axis the movement is the reverse of what it is on the other. Therefore the rocks on the tw sides of the fault plane will acquire tilts in opposite directions.

[c] Op. cit., pp. 168, 181.

[d] Mon. U. S. Geol. Survey Vol. XX, p. 196.

between the Silurian and Devonian, but dividing the rocks as well as might be the following thicknesses were found:

	Feet.
Carboniferous	2,160
Devonian	5,400
Silurian	1,000

IGNEOUS ROCKS.

Mr. Walcott noted occasional outbursts of acidic lavas in the Pahranagat Range, and Mr. Gilbert describes two large eruptions of rhyolite, one at the north end of the range and the other at Logan Pass at a cross fault.

STRUCTURE.

According to Mr. Gilbert the cross fault above-mentioned is a scisscors[a] fault, having such differential movement that all the strata to the north acquired a westerly dip, while those to the south are tilted toward the east. That portion of the range which lies north of the cross fault is divided into separate north-south ridges by north-south faults whose downthrow has been uniformly to the east. South of the pass the strata have a single, monoclinal, easterly dip.

ARROW CANYON RANGE.

The Arrow Canyon Range has not been visited and was only seen from some little distance. It is a continuation northward of that branch of Las Vegas Range which has been called the New Mountains. It has a general northwesterly trend, parallel with the main west arm of Las Vegas Range, and has a length of more than 20 miles. On the north it is separated from the Pahranagat Range by a narrow, transverse valley.

As seen from several points, the Arrow Canyon Mountains are made up of stratified rocks, well banded, but eroded so as to form massive cliffs. This is the appearance offered by the heavy Carboniferous limestone of this region, as shown just south of here in the New Mountains. It is possible, therefore, that the bulk of the range is Carboniferous. To the north also, in the Pahranagat Range, Carboniferous rocks are present in considerable quantity.

The strike of the strata is parallel with the trend of the range. Along nearly the whole of its western side the rocks are seen to dip into the range eastward at angles of from 15° to 20°. Farther north an area of apparently horizontal strata can be distinguished; so that the general structure of the range may be synclinal, corresponding to that of the New Mountains to the south, or it may be a general monocline dipping eastwardly, like the Pahranagat Range.

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[a] See p. 153 for definition.

LAS VEGAS RANGE.

Las Vegas Range forms an irregular group in the central portio of southern Nevada, lying just east of another irregular group, th Spring Mountain Range. Las Vegas Range has hardly any definit form, but a prolongation on the northwest gives it rather th aspect of having a northwesterly trend. This prolongation forms on arm of a rough V, of which the southern portion of the Meado Valley Range forms the other, the two uniting in a rugged cluste of mountains in the neighborhood of Gass Peak. Bisecting th angle of the V is a high, rocky ridge, which was not delineated on th Wheeler survey maps, and which the writer will call, for the purpos of description, the New Mountains.

It is peculiar that so prominent a ridge should have escaped map ping, for it comprises some of the highest mountains in the souther part of the State. On the eastern face of the New Mountains is sharp scarp of about 4,000 feet, rising from the foothills. This scar is often perpendicular for great heights, and is apparently inacces sible. The rocks are composed of massive limestone, beautifull banded. To the north the New Mountains become lower and ar separated from the Arrow Canyon Mountains, which are really portion of the same general range, by a transverse valley.

The southwest face of Las Vegas Range, facing Las Vegas Valley also possesses a steep slope, reaching 45° at some points.

No igneous rock whatever was found in Las Vegas Range.

SEDIMENTARY ROCKS.

CAMBRIAN.

From a point about 6 or 7 miles north of Mormon Wells, which is o the wagon trail crossing the southern portion of the range in a north easterly direction, southward probably to the end of the range, th rocks consist chiefly of bristly weathering siliceous, crystalline, chert limestone, often having a peculiar mottled structure, which is proba bly due to the rock having been originally made up of coral, no recrystallized and unidentifiable. This rock is lithologically identic with Cambrian limestones in the Highland Range west of Pioche.

On the divide south of Mormon Wells there are found thin, brow and red, sandy, and limy slates, changing to thin-bedded limestones These contain fossil remains, which are determined by Mr. Walcot as belonging above the *Olenellus* zone and probably to the Middl Cambrian. Fragments of white quartzite were found in the drift here which also suggest the existence of Lower Cambrian quarzites in th mountains.

The same ancient-appearing limestones are continuously expose along the road above mentioned, southwest nearly to Las Vegas Val ley. At this point they give way to the underlying Silurian.

Mr. R. B. Rowe noted that the first ridge west of Sheep or Gass Mountain (which ridge is here considered the northernmost part of Las Vegas Range) consists of beds of dark-blue and gray limestone, with white and reddish sandstone. Fossils collected in this locality were found by Dr. Girty to be chiefly Devonian, but to contain one Cambrian specimen. Therefore, probably both the Cambrian and the Devonian are here represented.

SILURIAN.

In the valley just northeast of Gass Peak, at the locality above mentioned, occur cherty, blue-gray, and siliceous, sometimes green and shaly, limestones similar to those of the Cambrian. The few fossils obtained from these rocks are regarded by Mr. Walcott as representing a horizon about the base of the Pogonip (Ordovician). Mr. Walcott determined *Orthis perveta* (?) and the tail of a trilobite belonging to the genus *Bathyurus*.

From this point to the northwestern end of the range the rocks appear to be all limestones, of the same ancient character as those already described, as specimens obtained here and there show. A similar limestone extends still farther northwest into the southern end of the Desert Range, and was followed continually along Las Vegas Valley to Indian Spring in the Spring Mountain Range. At Indian Spring Ordovician fossils were found.

About 6 miles northeast of Corn Creek, near the mouth of the first important canyon, Mr. R. B. Rowe found about 200 feet of dark blue limestone, containing immense numbers of gasteropods of enormous size, together with a few corals. The fossils collected by Mr. Rowe were determined by Dr. Girty as Ordovician.

DEVONIAN.

The existence of Devonian limestones in the ridge west of Sheep or Gass Mountain, at the north end of the range, has already been mentioned.

CARBONIFEROUS.

The Cambrian rocks in the neighborhood of Mormon Wells are apparently separated by a heavy east-west fault from the unmetamorphosed massive blue limestones which make up the greater portion of the New Mountain ridge and the auxiliary ridges to the east. In one of these auxiliary ridges a collection of fossils was obtained, which were found by Dr. Girty to be Upper Carboniferous. No north-south faults were determined, and the gentle folding, resulting in slight, alternating synclines and anticlines, suggests that rocks of the same horizon make up the New Mountains to the west.

According to the notes of Mr. R. B. Rowe, the mountains east of Las Vegas contain the Lower Carboniferous, the Carboniferous red

beds, and the Upper Carboniferous limestone, so far as can be seen from Las Vegas ranch.

From Sheep or Gass Mountain, in Las Vegas Range, specimens of *Goniatites* were brought and given to Mr. Rowe. The fossils seem to come from a soft shale.[a]

About 2 miles west of Sheep or Gass Mountain, in a spur of that range, about 5 or 6 miles north of the road leading from Corn Creek to Indian Creek, fossils were collected which were determined by Dr. Girty as Upper Carboniferous or Pennsylvanian, and in the same general region other fossils were collected which were determined by Dr. Girty as Lower Carboniferous or Mississippian. The ridge consists mainly of low hills, which are cut extensively by canyons.

Tertiary.—Mr. R. B. Rowe's notes on the Tertiary areas follow. At Las Vegas and in the immediate vicinity there are white beds of probably volcanic ash. From the valley some distance west of Las Vegas mastodon teeth were collected. About midway between Corn Creek and Tule Springs some mastodon teeth and bones have been found. They were situated in a clay bank some 10 or 15 feet high.

East of the range, at the summit of the pass between Las Vegas Valley and Muddy Creek, about 12 miles east of Las Vegas, are red and yellow Tertiary beds which dip toward the Colorado River at an angle ranging from 4° to 5°.[b]

The valley between Las Vegas, Tule Springs, and Corn Creek seems to be filled with lake deposits. About Tule Springs, and from there up the valley, are probably the remnants of an old, dry lake bed or playa. The deposits do not have the appearance of the Tertiary lake deposits, but resemble exactly the clay deposits in the present dry lakes. Underlying these is a gravel or talus deposit. The eroded dry lake beds extend from Corn Creek to Indian Creek.

PLEISTOCENE.

In Las Vegas Valley the Tertiary deposits so abundantly exposed in the region of Meadow Valley are hidden beneath Pleistocene accumulations. This valley is of the usual type of the desert valleys of Nevada, with gulch dumps fringing the mountains, and in the center a nearly level area of hard mud flats, or a playa. There has been no dissection of these deposits to reveal what lies beneath.

STRUCTURE.

The general folding in Las Vegas and New mountains has apparently resulted in a rough, shallow, disturbed northeast-southwest striking syncline. The nearly horizontal area in the central portion of the range

[a] These may be the same as some specimens of *Goniatites* received by Dr. Girty from Mr. Rowe's collection after the death of Mr. Rowe. They were considered by Dr. Girty as Lower (?) Carboniferous.

[b] These are the same as described by the writer under the head of "Meadow Valley Range."

belongs in the trough of the syncline, while at the northwestern end the dip of the northwest limb of the fold becomes 30° or 45° southeasterly, or even more. The syncline is succeeded by a much sharper anticline along the narrow valley separating the Desert and Las Vegas ranges. In the broad central portion of the syncline there has been irregular minor folding, chiefly along east-west lines, the dips generally being under 15°. At the southern end of the range the general strike appears to become east and west, and the dip about 20° north.

The main fold of Las Vegas Range, being at right angles to the general trend of the mountains, runs across Las Vegas Valley and is probably to be found in the Spring Mountain Range on the other side, where, indeed, it was thought to have been identified by the writer. Similarly, the various parallel ridges of limestone which run transverse to the general trend of the range are broken by the valley and find their continuation in the Spring Mountain Range opposite. Las Vegas Valley, therefore, differs from the most ordinary type in the Great Basin in that it is transverse to the general strike of the rocks.

In the region north of Mormon Wells there is a marked change from massive, unaltered, blue limestones, probably belonging to the Carboniferous, to altered, ancient-appearing, crystalline limestones, associated with shales carrying Cambrian fossils. The areas occupied by these different rocks may be easily sketched, since the erosion of each has resulted in peculiar forms. The Cambrian rocks have rounded topography, without scarps or evident structure, and weather brown, while to the north the blue-gray Carboniferous rocks have sharp scarped outlines with perfectly visible stratification. Inasmuch as the strike of the folds is here north and south, which carries the Carboniferous limestone directly into the Cambrian, there must be a fault between the two horizons, and this fault must have, as sketched, a direction somewhat north of west. The vertical displacement of the fault may be several thousand feet and has resulted in a downthrow to the north. There is no distinct break in the topography along the fault line.

The bold east face of the New Mountains suggests a more recent heavy fault, to whose displacement the scarp may perhaps be directly due.

The following notes on the structure were made by Mr. R. B. Rowe:

A sketch of the mountains of Las Vegas Range east of Las Vegas shows a constant dip of about 40° to the east. A hypothetical fault is also shown, which has the effect of bringing up the lower strata on the east side.

Near Corn Creek the rocks strike east and west and dip uniformly 30° to the north.

As has been noted, there is apparently a series of old, dry lake deposits in Las Vegas Valley, which are now being cut into by the arroyos. These, taken together with the fact that the surface rises about 400 to 600 feet between Tule Springs and Corn Creek

and that the same beds rise still higher beyond Corn Creek, indicate a comparatively recent elevation of the upper end of Las Vegas Valley.

On the east side of Las Vegas Range, the fact that the Tertiary beds dip slightly toward the Colorado at an angle of 4° or 5° suggests that the Las Vegas Range has been slightly raised since the general elevation of the region.

TIMPAHUTE RANGE.

The following summary of the Timpahute Range is taken from Mr. Gilbert's description.[a]

The Timpahute Range lies next west from the Pahranagat Range and immediately south of the Worthington Mountains. Its general trend is a little east of north and its length about 30 miles. The highest portion is Timpahute Peak, near the southern end.

SEDIMENTARY ROCKS.

At the south end of the range Mr. Gilbert[b] measured a thickness of 2,325 feet of strata showing the following section:

Section at south end of Timpahute Range.

	Feet.
1. Heavy-bedded gray limestone, light and dark	400
2. Yellow argillaceous shale:	
a. Yellow shale, 350 feet	
b. Yellow sandstone, 75 feet	925
c. Yellow and green shale, with fillets of fossiliferous limestone (*Conocoryphe*), 500 feet	
3. Purple, ripple-marked, vitreous sandstone, with bands of siliceous shale	1,000
Total	2,325

The fossils found in the shales above the basal quartzite fix the formation as Cambrian, and the basal quartzite is the same as the basal quartzite of the Highland Range Cambrian section and also the Prospect Mountain quartzite at Eureka.[c]

The northern portion of the range does not appear to have been described. Both to the east and to the west of it, in the Worthington Mountains and in the Pahranagat Range, are Silurian rocks, in part Lower Silurian. It is probable, therefore, that this north end of the Timpahute Range is in part Silurian and in part also Cambrian.

IGNEOUS ROCKS.

According to Mr. Gilbert,[d] Timpahute Peak is the center of a massive eruption of rhyolite, which connects with a similar eruption northeast of here in the Pahranagat Range by a line of volcanic hills which runs across the intervening valley.

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III.

[b] Ibid., p. 169.

[c] Ibid., p. 181; C. D. Walcott, Bull. U. S. Geol. Survey No. 30, p. 36, Bull. 81, p. 156; Arnold Hague, Mon. U. S. Geol. Survey Vol. XX, pp. 46, 189.

[d] Op. cit., p 123.

STRUCTURE.

The volcanic outburst at Timpahute Peak, according to Mr. Gilbert,[a] is on the line of a scissors fault, which has so displaced the strata that to the north of this fault they dip uniformly west while to the south they dip uniformly east. This fault is on the same line as a similar fault northeast of here in the Pahranagat Range, and another still farther northeast in the Hiko Range, and in each of these ranges the peculiar tilting of the strata above noted is found. In the Timpahute Range the sedimentary rocks south of the line of faulting are separated by north-south vertical faults which have a uniform downthrow to the west. Mr. Gilbert gives a section of the range showing this structure.

ORE DEPOSITS.

In the Cambrian shales at the southern end of the range, according to Mr. Gilbert,[b] are metalliferous veins.

DESERT RANGE.

The Desert Range is somewhat irregular and of moderate height. It is divided into two branches by an interior valley which reaches northward from the north end of the Spring Mountain Range. At its north end the Desert Range passes into the valley which separates the Timpahute from the Pahranagat Range.

SEDIMENTARY ROCKS.

The south end of the Desert Range was visited by the writer. It consists of altered, crystalline, light-gray limestone, brown weathering, often full of rounded, detrital quartz grains. There are also beds of black, dense limestone. Similar limestone contains Ordovician (Pogonip) fossils in the western part of Las Vegas Range. This limestone series can be distinguished extending northward fully halfway to the end of the range, at least 20 miles. It is possible that it may contain some of the Cambrian limestones which are hardly separable lithologically from the overlying Silurian.

Mr. F. B. Weeks[c] followed along the west side of the range and crossed the north end, at Mud Spring, in 1900. He found the bulk of the range to consist of stratified rocks, which he was inclined to consider as Silurian and Devonian, while on the north end these strata are replaced by volcanic rocks.

The following notes were made by Mr. R. B. Rowe:[d]

SILURIAN.

About 8 or 9 miles northeast of Indian Creek, in the first range on the west side of the dry lake which lies east of Indian Creek, and about

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 38, 39.
[b] Ibid., p. 181.
[c] Personal communication to the writer.
[d] *Taken from* his notebooks after his death by the writer.

4 miles north of the road from Indian Creek to Corn Creek, the section consists chiefly of dark-blue limestone, with light-blue arenaceous limestones and shaly limestones with chert layers. There are also a few layers of white sandstone, resembling quartzite. Fossils collected were regarded by Mr. Rowe as Ordovician, and his impression was corroborated by Dr. Girty's examination.

The rocks 4 miles east of Indian Creek are light-gray, arenaceous, and dark-blue limestones, with layers of chert and white sandstone, which is nearly a quartzite, as it is farther east. These rocks were regarded by Mr. Rowe as probably Lower Silurian.

DEVONIAN.

About 3 miles northeast of Indian Creek, in low hills south of the road leading to the lower end of Pahranagat Valley, and north of the road to Corn Creek, fossils were found in loose blocks of dark-blue limestone. These were regarded by Mr. Rowe as Middle Devonian, and were determined by Dr. Girty as probably Lower Devonian.

STRUCTURE.

At its southern end the range is separated on the southwest from Las Vegas Range by a narrow anticlinal valley, the rocks of the Desert Range dipping northwest on the northwest limb of the fold. The general strike here is northeast, and a series of parallel ridges has been eroded parallel to the strike. The dip continues in the same direction as far as the interior valley dividing the two chief branches, but becomes flatter, and the strike swings around more toward the north. On the western branch of the range, as seen from the south, the rocks are partly horizontal and partly strike a little east of north and dip uniformly west at angles not exceeding 15°.

The valley lying between the ridge lying west of Sheep Mountain and the range next west, or between Las Vegas Range and the Desert Range, was regarded by Mr. Rowe as anticlinal in structure.[a] The mountains on the two sides dip in opposite directions. On the western side Ordovician fossils were found; on the eastern side Carboniferous and Cambrian. There are probably large and numerous faults concealed by the talus. There is a great deal of plainly observable faulting at right angles to the strike. These faults are generally not large, but are abundant.[b]

REVEILLE RANGE.

The Reveille Range is separated on the north from the Pancake Range by a narrow transverse gap at Twin Springs. It extends southeastward from here a distance of about 60 miles, running obliquely across to the Timpahute Range.

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[a] This is the same anticlinal valley that was previously observed by the writer (see above) (J. E. S.).

[b] This whole paragraph is from Mr. Rowe's notes.

TOPOGRAPHY.

The range is somewhat irregular in its course and extent, which arises from its being made up largely of volcanic outbursts. This also accounts for the prevalent type of topography, which is similar to that of the Pancake Range to the north, showing low peaks and broad, gently sloping mesas, which are sharply cut into by the valleys eroded since the period of lava effusion. At one or two points, however, such as that near the old mining camp of Reveille, patches of older Paleozoic strata, and of older volcanics than those which form the mesa-like forms, emerging from the younger lavas, offer a series of sharp, irregular peaks and better developed valleys.

SEDIMENTARY ROCKS.

According to Mr. Gilbert,[a] the Paleozoic strata which form the core of the Reveille Range are exposed at but two points, one at Reveille and the other 60 miles farther south. In both these cases the rocks dip to the west, the dip being steeper at the more southern exposure. At Reveille the strata are of limestone and quartzite.

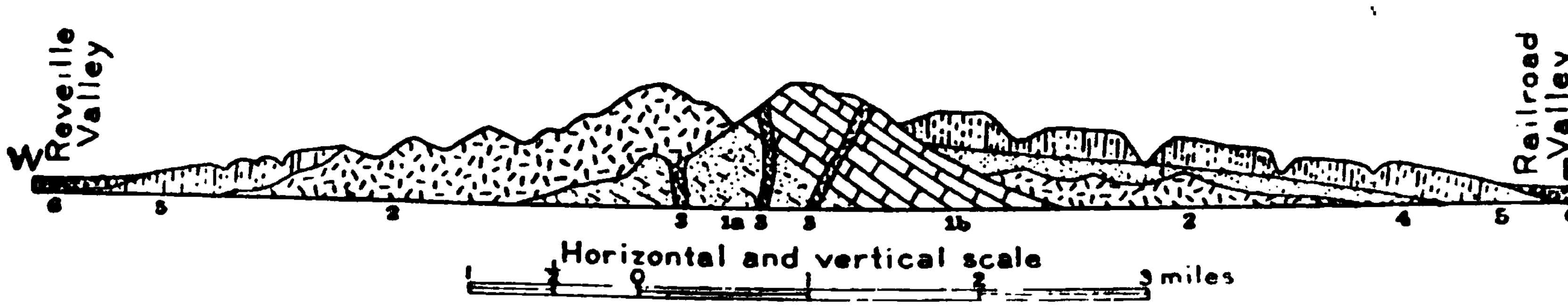

FIG. 21.—Generalized sketch cross section of Reveille Range near Reveille.

1. Paleozoic (Cambrian) quartzite (1a) and limestone (1b).
2. Rhyolite.
3. Porphyry dikes.
4. Rhyolite sandstone.
5. Olivine-basalt.
6. Valley wash (Pleistocene).

The more northerly locality was visited by the writer, and so far as a hasty examination could determine, the lowest formation seems to be a hard white quartzite, surmounted by a dark-blue massive limestone, much altered and carrying only indeterminable fossils. As seen from Reveille, the mountain to the east seems to have at its base about 1,500 feet of quartzite, capped by 2,000 feet of limestone. The strike is north and south, the dip W. 15° or 20°. If the section is actually as supposed, the rocks can hardly be other than the Cambrian quartzite and limestone of the Eureka section.[b]

The strata are traversed by many porphyry dikes, probably connected with the rhyolitic outbursts. The rhyolite wraps around these limestone mountains in such a way as to show that they were already sharp peaks previous to the pouring out of the lava (fig. 21).

[a] U. S. Geog. Surv. W. One hundredth Mer., Vol. III, p. 37.

[b] Ibid., p. 179, Mr. Gilbert cites Prof. J. J. Stevenson as having recognized Carboniferous rocks at Reveille. In view, however, of the confusion of Carboniferous and older rocks at this period (several other Cambrian areas having been referred to the Carboniferous) and in view of the fact that the lithology of the region is that typical of the Cambrian here, but probably not characteristic of the Carboniferous, the writer has decided to retain in the mapping the Cambrian color.

TERTIARY.

In the transverse cut across the northern end of the mountain range at Twin Springs the section consists of volcanic rocks and water-laid tuffs and gravels derived from them. At the base of the section is altered biotite-rhyolite, and above comes about 600 feet of white rhyolitic sandstone. This is capped by 100 feet of rhyolitic tuffs and gravels, surmounted by about 100 feet of augite-olivine-basalt.

IGNEOUS ROCKS.

As already stated, most of the range is made up of igneous rocks. Those which outcrop most upon the surface appear to belong to the later, more basic lavas, of which the augite-olivine-basalt at Twin Springs is a member. This same basalt is found on the east of the higher mountains between Twin Springs and Reveille. Beneath this basic lava, however, the older biotite-rhyolite frequently comes to the surface and is distinguishable by its more rugged topography.

RELATIVE AGE OF IGNEOUS ROCKS.

In the section at Twin Springs it is shown that the rhyolite is older than the basalt. Between Twin Springs and Reveille the intervening series of tuffs disappears with increasing elevation, and the basalt mantles around the base of craggy rhyolite eminences in such a way as to show that they were already mountains before the basalt appeared. The disappearance of the intervening tuffs also suggests that the higher rhyolite peaks were mountains in the lakes in which the rhyolitic tuffs were laid down.

ORE DEPOSITS.

In the vicinity of Reveille are mines which formerly were very profitable, but which are now almost entirely deserted. The mines are situated in a patch of limestone and quartzite surrounded by volcanic rocks, and the ores probably have genetic connection with the dikes which traverse the sedimentaries.

BELTED RANGE.

The Belted Range runs southward from the Reveille Range and forms, in its southern part, the eastern boundary of the Amargosa Desert. It is somewhat irregular, but has a general north-south trend. At its northern end it is separated from the Reveille Range by a slight interval of low, lava-covered country, while at its south end it is separated from the low mountains lying north of Pahrump Valley by a considerable intervening area of Pleistocene subaerial deposits. Its name has probably been given to it on account of the horizontal banding visible for a long distance on its steep sides.

SEDIMENTARY ROCKS.

CAMBRIAN.

The Belted Range was crossed by Mr. Gilbert during his reconnaissance for the Wheeler survey. He notes that at White Bluff Spring and for several miles southward the range shows an axis of quartzite.[a] This he regards as the same formation as a similar quartzite recognized in the Timpahute Range, which is of Cambrian age.

The whole southern portion of the range, as seen from the south, is of stratified rocks, apparently chiefly limestones. It is probable that this portion of the range forms a part of the general Cambrian-Silurian area, which includes part of the northern end of the Spring Mountain Range, a large portion of Las Vegas Range, and at least the southern end of the Desert Range.

IGNEOUS ROCKS.

VOLCANIC ROCKS.

Mr. Gilbert[b] found that near White Bluff Spring the principal mass of the range was of lavas, which nearly hid the Paleozoic axis. These lavas stretch northeastward and connect with those of the Reveille Range, and also extend westward, forming low mountains, which divide the Ralston Desert from the Amargosa Desert. In these mountains Fortymile Canyon is cut. They extend westward at least as far as Oasis Valley, which is the head of the Amargosa River; and they stretch northward over the whole of the Ralston Desert.[c]

STRUCTURE.

The probable structure of the Paleozoic southern portion of the range could only be uncertainly made out from a distant view. In general, however, the rocks appear nearly horizontal, but they sometimes dip as much as 15° at least. The general strike is parallel with the trend of the range.

SPRING MOUNTAIN RANGE.

The Spring Mountain Range is an exceedingly irregular-shaped group of mountains, lying southwest of Las Vegas Range, and separated from the Kingston Range, farther south, by the Pahrump Valley. The general trend of the range is northwest and southeast, and its length in this direction is about 60 miles, and at its northern end, in the neighborhood of Charleston Peak, the total width is as much as 30 miles. This peak constitutes the highest portion of the range, being 10,874 feet above the sea, and is a conspicuous landmark. This range is divided into numerous ridges, which run in many dif-

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 123. [b] Ibid. [c] See p. 182.

ferent directions without much visible system. At at least two points at the northern base of the range there occur warm springs, namely, Indian Spring and the spring at White's ranch in Pahrump Valley. This is interesting, since the range contains few igneous rocks.

SEDIMENTARY ROCKS.

CAMBRIAN.

The north end of the range was traversed from Indian Spring southwest, by way of Hornet Spring, to White's ranch. At Indian Spring are limestones carrying Lower Carboniferous fossils, as determined by Dr. Girty. Following up the canyon which leads southward to Hornet Spring a great thickness of limestones was passed through, all striking a little north of east, parallel in general with the north end of the range, and dipping northward at angles varying from 20° to 65°. The limestone is all thin bedded. North of the summit of the pass comes in a thin bed of vitreous quartzite. At the summit is a thick white vitreous quartzite, often coarse and nearly conglomerate, beneath the limestone. Just south of the summit there is an east-west fault which cuts off the quartzite and again brings down the limestone into the section. In this limestone, at a point half a mile south of Hornet Spring, were found abundant fossils, which have been determined by Mr. Walcott to be Cambrian, probably Middle Cambrian. These fossils are in blue-gray semicrystalline limestone like that found above the quartzite north of the fault. It is probable, therefore, that some of the limestones exposed in ascending the canyon north of the summit belong to the Cambrian, and that these pass upward into the Lower Carboniferous limestones at Indian Spring without any marked stratigraphic or lithologic break. The white quartzite at the summit is also probably Cambrian, since it underlies the limestones.

The thickness of the section shown north of the fault has been estimated at about 17,000 feet, of which an estimated thickness of 2,000 feet may be taken for the quartzite, leaving 15,000 feet for the limestones.

The Cambrian limestones near Hornet Spring are continuous only a short distance south, when they give place abruptly to Carboniferous limestones, the two being apparently separated by an east-west fault, parallel with and only some 3 miles south of the one already mentioned. From this point to the southern end of the range it is probable that no Cambrian rocks are exposed, since Carboniferous fossils are found at many points.

Mr. R. B. Rowe's notes[a] on the Cambrian may be summarized as follows:

About 7 miles south of Indian Spring, in a high range of hills, were found greenish-yellow shales, with thin, dark sandstone bands

[a] Made in 1900-1901. Taken from his notebooks, after his death, by the writer.

containing trilobite and linguloid shells. These were underlain by brownish massive limestone, containing great numbers of trilobite remains. These Cambrian rocks appear to be directly overlain by dark-blue and gray, probably Carboniferous, limestones. The dip of the Cambrian rocks is due north, while that of the Carboniferous is to the south, suggesting an unconformity, although the two formations are divided by a covered wash 2½ miles wide. The Cambrian may be separated from the Carboniferous here by a fault or by an unconformity.

In the whole Spring Mountain Range nothing was found between the Cambrian and the Carboniferous suggesting a hiatus between the two periods.

On the southwest side of a traversed line from Indian Creek to Tule Springs (on the east side of Las Vegas Range), from a distance about 5 miles east of Indian Creek to about 5 miles west of Corn Creek, the low hills near the valley are Cambrian, and probably some on the north side of the valley also. About 6 or 7 miles southwest of Corn Creek, on the south side of the valley, there is apparently a fault, bringing the Cambrian against what is probably the Carboniferous (fig. 22). The Cambrian comprises a number of parallel ridges, with steep south-facing escarpments and with strata dipping north. Between the ridges is a covering of talus.

CARBONIFEROUS.

At Indian Spring Lower Carboniferous fossils were found in a black, fetid, semicrystalline limestone with brown sandy beds. They were determined by Dr. Girty as follows:

Ptilodictya sp.
Chonetes sp.
Productus cf. mesialis.
Orthothetes n. sp.

Dr. Girty remarks that this fauna can not with certainty be placed in the Lower Carboniferous, though it is probably of that age.

These rocks probably constitute a relatively narrow strip at the northern end of the range, and are succeeded on the south by older strata, as above described.

A few hundred yards south of the ranch at Indian Spring the following Carboniferous fossils were collected by Mr. F. B. Weeks, in 1900,[a] and were determined by Dr. Girty:

Zaphrentis sp.
Rhipidomella oweni.
Orthothetes inæqualis.
Productella concentrica ?
Productus burlingtonensis.
Productus semireticulatus.
Productus cf. P. lævicosta.
Spirifer keokuk.
Spirifer near neglectus.
Seminula humilis.
Camarotœchia sp.

[a] Personal communication to the writer.

At the same locality Mr. R. B. Rowe[a] noted and collected Lowe Carboniferous fossils. The rock is massive and cherty blue and gra limestone, with reddish and yellowish shaly and arenaceous layer The section is as follows from the top downward:

Section near Indian Springs.

1. Massive cherty blue limestone, poor in fossils. Thickness unknown. Unconformity.
2. Red shales with thin bands of blue limestone and yellowish calcareous san stone, about 300 feet. Lower Carboniferous fossils.
3. Massive blue limestone filled with crinoids and corals. Thickness unknown.

Fossils collected from the red shales underlying the upper blu limestone unconformably were determined by Dr. Girty to be Upp Carboniferous or Pennsylvanian, rather than Lower Carboniferou Therefore the line between Upper and Lower Carboniferous li between 2 and 3.

About half a mile south of Indian Creek, fossils collected by M Rowe from the rocks that apparently underlie the red beds fro which the Upper Carboniferous fossils were taken, were found l Dr. Girty to be Lower Carboniferous or Mississippian.

About 7 miles south of Indian Creek, the following Carboniferou section was found by Mr. Rowe, overlying the Cambrian. The se tion is given from the top down.

Section 7 miles south of Indian Creek.

1. Massive dark-blue limestone, weathering rough, and containing white calci spots.
2. Light-gray, massive, unfossiliferous limestone.
3. Massive dark-blue limestone, like No. 1.

About 3 or 4 miles south of Hornet Spring fossils are found in yellov weathering, blue, shaly, argillaceous, cherty limestone, which lies the south of the thin-bedded Cambrian limestone, and is not readi separable from it in the field. In this yellowish, shaly limestor *Fusulina cylindrica* was found, and the horizon was therefore dete mined by Dr. Girty as Upper Carboniferous. Southward from her as far as the point where the road enters the foothills, the rocks a all similar thin-bedded limestones.

To the east, Charleston Peak and the high ridge south of it a formed of massive limestone, which has all the appearance of belon ing to the great Carboniferous series. Mr. Turner has informed tl writer that Carboniferous fossils have actually been found on Charle ton Peak by surveyors.

On the east side of Charleston Canyon Mr. Rowe[b] noted that tl range seemed to be made up of Carboniferous limestone. Well dov in these strata some fossils were found, chiefly *Fusulina*. The roc are light-gray arenaceous limestones, containing considerable cher

[a] Taken from Mr. Rowe's notebooks of 1900 and 1901, after his death, by the writer.
[b] Notebooks. See above.

Fossils collected by Mr. Rowe were identified by Dr. Girty as Pennsylvanian or Upper Carboniferous.

In the foothills of the range, just east of White's ranch, in Pahrump Valley, a collection of Lower Carboniferous fossils was obtained, as determined by Dr. Girty:

Zaphrentis sp.
Aulopora sp.
Fenestella sp.
Leptæna rhomboidalis.
Chonetes planumbonus?
Productus cf. mesialis.
Spirifer cf. grimesi.
Spiriferina sp.
Athyris lamellosa.
Seminula sp.
Rhynchonella sp.
Beyrichia sp.
Phillipsia sp.

About 7 miles north of the above locality the rocks are also Carboniferous, according to a note supplied by Mr. Turner. Fossils were collected by Mr. F. C. Boyce from near Fremont Wash, 7½ miles north-northeast of Manse post-office (White's ranch). On these Mr. Schuchert, of the United States National Museum, reported:

The fossils * * * are of Carboniferous age. There are two species of *Zaphrentis*, a *Syringopora* near *multattenuata* and a *Spirifer* fragment too small for determination.

South of Manse the range was not visited by the writer, but he observed that the same series of rocks extended east and south for a number of miles. Mr. Gilbert, however, observed Carboniferous rocks east and south of here, at Cottonwood Spring[a] and at Olcott Peak.[b] At the first-named locality Mr. Gilbert made the following section:

Section at Cottonwood Spring.

	Feet.
1. Massive red and yellow sandstone:	
a. Yellow, 250 feet	
b. Red, 150 feet	1,000
c. Yellow, 200 feet	
d. Red and shaly, 400 feet	
2. Bedded, fine-grained to saccharoid limestone, gray and cream-colored; beds separated by shaly layers so as to weather in steps. [*Phillipsia* (?), *Macrocheilus* (*non des.*), *Naticopsis*, *Aviculopecten*, *Avicula*, *Meekella*, *Myalina*, *Productus semireticulatus*, *Spirifer lineatus*, *Athyris subtilita*, *Synocladia*]	500
3. Massive gypsum, white and red, in lenticular masses	0 to 70
4. Gray, massive, cherty limestone:	
a. Limestone [*Meekella*, *Productus*, *Chætetes*, *Syringopora*], 250 feet	
b. Unseen; red (shale ?), 25 feet	475
c. Limestone, 200 feet	
5. Friable sandstone, in places shaly or marly; variegated with brilliant iron colors	350
Total	2,395

The fossils here show that the rocks of the section are Upper Carboniferous. At Olcott Peak the fossils, according to Mr. Gilbert, are Lower Carboniferous.

[a] U. S. Geog. Surv. W One Hundredth Mer., Vol. III, p. 166. [b] Ibid., p 32.

At Mountain Spring, a point about 6 miles west of Cottonwood Spring, Mr. Gilbert[a] notes that Mr. C. A. Ogden obtained a set of fossils of facies older than the Coal Measures. Among the forms are *Phillipsia*, *Spirifer* (two species of Devonian aspect), *Rhynchonella*, *Hemipronites*, *Athyris* (distinct from *A. subtilita*), *Chonetes*, *Terebratula* (?), *Productus* (like *P. subaculeatus*), and *Fenestella*. The horizon is referred to the Lower Carboniferous.

The following valuable observations on the Carboniferous of the southern portion of the Spring Mountain Range were made by Mr. R. B. Rowe in 1900–1901:[b]

Lower Carboniferous.—About 6 miles south of Good Spring, Lower Carboniferous limestones are found, probably separated by an overthrust fault from Mesozoic strata. The Carboniferous is much altered, but in some of the layers good corals are found. The Mesozoic beds consist of rich shales and sandstones.

At Mountain Spring fossil-bearing Lower Carboniferous beds not more than 3,000 feet thick occur. Above these are Carboniferous red beds, at least 2,000 feet thick, which are overlain by Upper Carboniferous limestone, from 500 to 600 feet thick. Beneath the Lower Carboniferous is a light-gray arenaceous limestone. The line between this limestone and the overlying Carboniferous limestone is sharply drawn.[c]

Carboniferous red beds (*Upper Carboniferous*).—About one-half mile west of Mountain Spring, on the road to Mule Spring, is a dark fossiliferous limestone lying upon a light-colored, much-altered limestone. These limestones are probably Lower Carboniferous. In the valley west of Mountain Spring they are overlain by a considerable thickness (2,000 feet?) of red Carboniferous shales and sandstones, which form a greater portion of the Mule Spring Mountains and are capped by the Upper Carboniferous fossil-bearing cherty limestones. On the east side of Mule Spring Mountain the red shales and sandstones are found at the base, capped by the Upper Carboniferous limestones.

For 8 or 10 miles north and northwest of Mule Spring the Upper Carboniferous is overlain by the fossiliferous Jurassic.[d] There are no red beds or conglomerates between the two formations, although some of the topmost layers of the Carboniferous are conglomeratic. The thickness of the Upper Carboniferous limestone is about 500 feet. The thickness of the Upper Carboniferous red shales and sandstones exposed in this region must be two or three times as much.

Between Mule Spring and Mountain Spring red sandstone occurs with a northerly strike and a dip 20° west.

At Mountain Spring the Carboniferous red beds lying above the

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III., p. 180.

[b] Taken from his notebooks, after his death, by the writer.

[c] See citation from Mr. Gilbert on region of Mountain Spring, above.

[d] Mr. Rowe's field determination.

Lower Carboniferous are at least 2,000 feet thick, and are overlain by 500 to 600 feet of Upper Carboniferous limestone.

On a divide along the road between Good Spring and Cottonwood Spring, Carboniferous red beds immediately underlie the fossiliferous Jurassic,[a] as is the case also at Good Spring; but about 6 miles east of Cottonwood Spring the Jurassic[a] lies directly upon the Upper Carboniferous limestone.

South of Indian Spring, at the northern end of the range, are red shales and sandstones underlying massive blue limestones unconformably. The shaly layers and the thin limestone bands in these red beds are fossiliferous. They were determined by Dr. Girty as Upper Carboniferous. The formation here has a thickness of about 300 feet. It overlies blue massive Lower Carboniferous limestone.

Upper Carboniferous limestone.—For 8 or 10 miles north and northwest of Mule Spring the folded Upper Carboniferous is overlain by fossiliferous Jurassic.[a] The Upper Carboniferous limestone is about 500 feet thick; the Upper Carboniferous red shales and sandstones about 2,000 feet thick. The Upper Carboniferous limestone may be divided about equally into (1) upper cherty massive limestone, containing abundant fossils; (2) lower light-gray, massive limestone, containing a few fossils. The two portions are divided in some places by layers of red shales and sandstones, as, for example, at Cottonwood Spring. One-half mile west of Mule Spring Mr. Rowe collected fossils determined by Dr. Girty as Pennsylvanian or Upper Carboniferous.

On the escarpment of the west side of the Mule Spring Mountain there is exposed the Upper Carboniferous limestone, underlain by the red shale formation.

At Mountain Spring, Carboniferous red beds are at least 2,000 feet thick. They overlie about 3,000 feet of Lower Carboniferous strata, and underlie Upper Carboniferous limestone from 500 to 600 feet thick. Beneath the Lower Carboniferous is a light-gray arenaceous limestone, containing no discovered fossils.

At Cottonwood Spring fossils were collected from the Upper Carboniferous by Mr. Rowe, and were subsequently identified as such by Dr. Girty.[b] Upper Carboniferous beds were followed some distance south of Cottonwood Spring; also east of Cottonwood Spring.

In the hills north and northwest of Cottonwood Spring the Upper Carboniferous is overlain by conglomerate and strongly cross-bedded coarse sandstone, in beds 10 or 20 feet thick. Above these conglomerates are shales and gypsum beds, above which again are the fossiliferous arenaceous Jurassic[c] limestones.

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[a] Mr. Rowe's field determination.

[b] See citation from Mr. Gilbert on Upper Carboniferous at Cottonwood Spring, above.

[c] Mr. Rowe's field determination.

About 3 miles southeast of the summit, between Good Spring and Wilson's ranch, the Lower Carboniferous of the Bird Spring Range lies against the Upper Carboniferous and Jurassic,[a] being separated by a fault.

About 6 miles east of Cottonwood Spring, directly overlooking Las Vegas Valley, is an escarpment consisting of Upper Carboniferous beds. These are underlain by heavy shales and brownish micaceous sandstone, much cross-bedded. At this point the red beds seen are not over 50 feet thick.

Between Good Spring and Cottonwood Spring the Upper Carboniferous repeatedly occurs. North of Good Spring a low knoll of the Upper Carboniferous occurs west of the road, up to the Mesozoic cliff at the foot of Olcott Peak (Potosi Mountain). Near the summit both Carboniferous and Mesozoic rocks occur along the road. East and north of Cottonwood Spring are apparently Carboniferous rocks, while south and west are Mesozoic.

About 12 miles north of Good Spring, near the divide between Good Spring and Cottonwood Spring, is a small area of Upper Carboniferous, occupying a fault zone which separates the probably Mesozoic red sandstones and shales from the Lower Carboniferous limestones which make up Olcott Peak.[b] On the east side of Olcott Peak, about 10 miles north of Good Spring, fossils were collected by Mr. Rowe that were identified by Dr. Girty as Upper Carboniferous or Pennsylvanian.

About 3 miles northeast of Good Spring, in the Bird Spring Mountains, there was noted about 425 feet of gray, brownish, and pinkish arenaceous limestone. Fossils collected at three different horizons in the series by Mr. Rowe were determined by Dr. Girty to be Upper Carboniferous or Pennsylvanian.

At Good Spring the following section was obtained, from the top down:

Section at Good Spring.

	Feet.
Consolidated ancient talus	6–10
Arenaceous light-brown limestone, rather thin bedded	610
In part yellowish and reddish shales and sandstones, which make the same red terrane as shown at the eastern base of Olcott Peak	760
Heavy conglomerate, subangular pebbles	50
Gray limestone with some red and pinkish arenaceous layers and cherty layers; the upper 50 feet is conglomeratic and contains large quartzite bowlders; fossils abundant in the conglomerate, less so in the rest	300

Mr. Rowe regards the 50 feet of conglomerate underlying the red beds as a basal conglomerate, and the conglomerate at the top of the limestone beneath as an apical conglomerate. Fossils of the lower conglomerate collected by Mr. Rowe are regarded by Dr. Girty as probably Permian, or uppermost Carboniferous. Fossils collected

[a] Mr. Rowe's field determination.

[b] See citation from Mr. Gilbert on Lower Carboniferous at Olcott Peak, above.

from the arenaceous limestone overlying the red beds are regarded by Dr. T. W. Stanton as not younger than Trias, and perhaps as old as the Permian.

Fossils collected from the Upper Carboniferous at Cottonwood Spring by Mr. Rowe are regarded as possibly Permian by Dr. Girty.

East and southeast of Good Spring, along the road to Manvel, occurs the contact of the Mesozoic and Carboniferous. On the east and north are Upper Carboniferous beds with fossils identical with those found at Good Spring. The red shales, sandstones, and conglomerates which lie between the Upper Carboniferous and Jurassic at Good Spring and at Olcott Peak are wanting about 5 miles southeast of Good Spring, and the calcareous sandstones of the Jurassic lie directly upon the Carboniferous. The Upper Carboniferous also has lost at this point the conglomerate which lies at its top at Good Spring.

The mountains near Good Spring are chiefly limestones, with considerable sandstone underlying. Fossils collected by Mr. Rowe from the lowest rocks exposed in the Bird Spring Range[a] were identified by Dr. Girty as Pennsylvanian or Upper Carboniferous.

Correlation with Grand Canyon section.—In the Grand Canyon and Colorado Plateau region the Carboniferous was studied in the course of the Wheeler survey by Messrs. Gilbert and Marvine. It was divided into the Aubrey limestone, the Aubrey sandstones, and the Red Wall limestone. The Aubrey limestone has a maximum thickness of 820 feet, and contains fossils suggesting the Permo-Carboniferous of the Mississippi Valley, and indicating the close of the Carboniferous age. The limestone is characterized by a great abundance of chert, which toward the top sometimes constitutes half the mass. Near the middle it is in some places interrupted by a bed of shale with gypsum.

The Aubrey sandstone has a thickness along the Grand Canyon of about 1,000 feet. A portion is massive and cross-bedded, another portion soft and gypsiferous. The sandstones contain no fossils, but an intercalated limestone bears Coal Measures shells.

The Red Wall limestone has a gray color on fresh fracture. It is heavy-bedded and massive. Near the top sandstone alternates with the limestone for from 200 to 500 feet. Through its lower half the limestone is interrupted by occasional shaly bands. The average total thickness is 2,500 feet. Fossils are abundant near the top, but in the lower portions are difficult to find. The lowest fossils were found a little below the middle of the series, and were doubtfully referred to the Lower Carboniferous. The fauna of the upper portion is rich, and, while different from that of the Aubrey limestone, is referable to the Coal Measures.

Mr. Gilbert[b] was not able to exactly correlate the Colorado Plateau

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[a] The southern prolongation of the Spring Mountain Range, lying east of Good Spring.

[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 177, 178, 179.

and Grand Canyon Carboniferous with the Carboniferous series i
the Spring Mountain Range. Nevertheless, the Carboniferous de
scribed by Mr. Rowe seems to bear a general resemblance to th
Colorado Plateau and Grand Canyon section. This correlation ma
be suggested:

Correlation of Spring Mountain and Grand Canyon sections.

Gilbert and Marvine, Grand Canyon section.	Rowe, Spring Mountain section.
Aubrey limestone, maximum 820 feet, Upper Carboniferous.	Upper Carboniferous limestone, 500-600 feet.
Aubrey sandstone, 1,000 feet, probably Upper Carboniferous.	Carboniferous red sandstone, shale, and co glomerate, 1,000-2,000 feet, probably Upp Carboniferous.
Red Wall limestone, Upper and Lower Carboniferous, 2,500 feet.	Lower Carboniferous limestones, 3,000 feet.

MESOZOIC.

Eight or 10 miles north and northwest of Mule Spring the Uppe
Carboniferous is overlain by fossiliferous Jurassic.[a] Among the fo
sils seen in the Jurassic *Pentacrinus astericus*[a] is very abundant.

About 4 miles west of Cottonwood Spring is a great escarpment, a
least 2,000 feet high. It consists of two terranes, the lower being re
shales and sandstones, making up about one-third of the heigh
Above this is a heavy yellow sandstone, containing occasional re
lenses. These rocks are probably Mesozoic.

To the east and northeast of Cottonwood Spring the hills appea
to be Mesozoic also.

In the hills north and northwest of Cottonwood Spring the Uppe
Carboniferous is overlain by beds of conglomerate and coarse, strongl
cross-bedded sandstone. These beds are from 10 to 20 feet thicl
Overlying these conglomerates are 100 feet or more of intercalate
white gypsum beds and red shales, and above these lies the fossi
iferous arenaceous limestone of the Jurassic.[a] Near the bottom of th
fossiliferous beds is a stratum containing a multitude of *Gryphæa*.[a]

About 10 miles north of Wilson's ranch, the Carboniferous lime
stone has been brought above massive red Mesozoic sandstone by
great overthrust fault. Between Wilson's ranch and Red Spring th
Mesozoic is also found. About 8 or 10 miles north of Wilson's ranc
the same overthrust fault as mentioned above was found. The ma
sive Mesozoic sandstone here is colored pink, bright vermilion re
and white. It is strongly cross bedded everywhere.

Between Wilson's ranch and Cottonwood Spring the low hills sho
strata which contain Jurassic fossils.

About three-quarters of a mile south of the summit, between Goo
Spring and Wilson's ranch, the Jurassic lies at the foot of a ridg
made up of Upper Carboniferous rocks, the Carboniferous being sep
rated from the Mesozoic by a fault.

[a] Mr. Rowe's field determination.

At the foot of Olcott Peak there is a cliff composed of Mesozoic rocks. From here the Mesozoic turns east and crosses the road before the summit between Good Spring and Cottonwood Spring is reached. Near the summit Carboniferous and Mesozoic alternate along the road. From the summit to Cottonwood Spring, Mesozoic rocks occur on both sides of the road. The rocks in the hills south and west of Cottonwood Spring are Mesozoic.

On the great fault line which separates the Mesozoic from the Carboniferous between Good Spring and Cottonwood Spring, the fossiliferous Jurassic apparently lies beneath the red and white sandstones which form the cliffs west of Wilson's ranch.

At Good Spring the Mesozoic was found overlying the Carboniferous. The following is the section:

Section of Mesozoic at Good Spring.

	Feet.
1. Arenaceous limestone	610
2. At base yellowish and reddish sandstone about 50 feet thick. Above this are layers of red and yellowish shale. This may be the same red terrane which shows at the eastern base of Olcott Peak	760
3. Heavy conglomerate	50
4. Gray limestone, with some layers of red or pinkish arenaceous limestone, and abundant layers of chert. The upper 50 feet contains numerous large quartzite bowlders	300

Fossils collected from No. 1 were described, after a preliminary examination by Mr. T. W. Stanton, as belonging to a horizon not younger than the Triassic, and possibly as old as the Permian. The fossils collected from No. 4 were judged to be questionably Permian by Dr. Girty.

East and southeast of Good Spring, along the road between Good Spring and Manvel, the road runs along the contact of the Mesozoic and the Carboniferous. The red shales, sandstones, and conglomerates which lie between the Upper Carboniferous and the Jurassic at Good Spring and Olcott Peak are wanting about 4 or 5 miles southeast of Good Spring, and the calcareous sandstones of the Jurassic lie directly upon the Carboniferous.

About 6 miles south of Good Spring the Lower Carboniferous seems to be overthrust upon the Jurassic.

IGNEOUS ROCKS.

At Good Spring, near the southern end of the range, Mr. Gilbert[a] noted a flow of basalt. Other than this no igneous rock is known in the whole range. Mr. Rowe's notes record the following:

At the Keystone mine, at the southern end of the range, there is an acid porphyry dike running N. 17° E. Along both sides of this, in a talcose material, gold is found. The dike dips from 35° to 40° W.

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III.

East of Bird Spring Range, in the direction of the Colorado River, there appear to be extensive lava fields.

STRUCTURE.

The general observed strikes and dips of the strata in the Spring Mountain Range have been plotted by the writer from different points. The results show more complex folding than in any of the mountain ranges to the north and east, and to this folding the irregular shape of the range is probably due. In an east-west section the general structure of the range seems to be a broad syncline, with a number of minor folds, of little importance, and all part of the great fold. The axis of this syncline runs northeast and southwest, transverse to the general trend of the mountains and parallel to the axes of the folds in Las Vegas Range, already described, and well over to the western side of the mountains. Mr. Gilbert[a] gives a section of the Carboniferous rocks at Cottonwood Spring, which shows the southeasterly side of this general syncline.

At a point on the eastern face of the range, due southwest from Corn Creek in Las Vegas Valley, a sharp, slight anticline, constituting a wrinkle in the general syncline and with a parallel axis, may be observed. On the other side of the range a similar anticline runs along the foothills northward from White's ranch for some distance. It afterwards appears to pass into and occupy the narrow north-south valley between the northern end of the Spring Mountain Range and the low clusters of mountains immediately west.

In a north-south section, however, the structure of the Spring Valley Range appears to be anticlinal, the strike at both the north and south end being in general east and west, and the dip varying up to 65° N. at the north end and up to about 20° S. at the south end.

Taken altogether, therefore, the range exhibits a peculiar fold, anticlinal in a north-south section, and showing a slightly complicated or wrinkled synclinorium in an east-west section. The portions of the center of the syncline that should lie flat dip north and south at each limb of the anticline.

Except at the northern end the rocks of the range are chiefly Carboniferous. At the northern end the Cambrian rocks are brought up, probably, by at least two heavy east-west faults. The northernmost of these faults observed lies north of Hornet Spring, and has apparently brought the Cambrian quartzite into juxtaposition with the Cambrian limestone, which stratigraphically overlies it. The throw of the fault must be at least 1,000 feet, and its course can be traced across the country by the break in the quartzite. The second fault lies 3 or 4 miles south of here, just south of Hornet Spring. It is probably parallel to the first, although it can not be traced so easily,

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III.

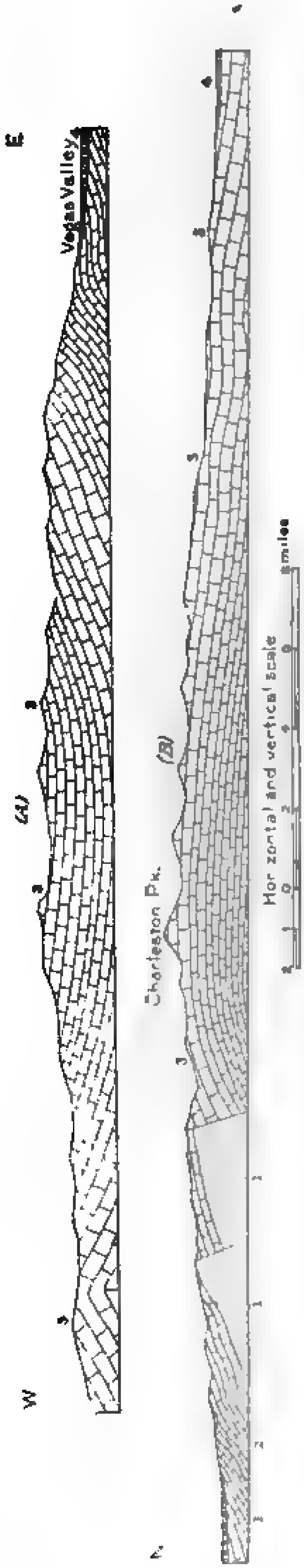

FIG. 22.—A. Generalized sketch section across Spring Mountain Range north and south. B. Generalized sketch section across Spring Mountain Range east and west at right angles to A.

1. Cambrian quartzites chiefly
2. Heavy limestones, including probably Cambrian, Silurian, and Devonian
3. Carboniferous limestones underlain in the deeper parts probably by Cambrian rock
4. Valley wash

since it separates one limestone body from another. But the limestone to the north is probably Middle Cambrian, while to the south it is Upper Carboniferous. A vertical displacement of several thousand feet is here evidenced, the downthrow being to the south, as is also the case with the first fault mentioned.

These two heavy faults have the same general direction as the heavy fault described in Las Vegas Range, and like it they have no primary effect on the topography, being marked by no scarps (fig. 22).

A third fault is suspected at the northern end of the range, separating the Carboniferous limestone from the supposedly Silurian limestone of the immediately adjacent Desert Range. If this fault exists, its downthrow is, like the others, to the south (fig. 22).

The following important observations on structure have been taken directly from Mr. Rowe's notebooks, after the writing of the above:

About 10 miles west and northwest of Mule Spring, the Upper Carboniferous is thrown into a series of minor faults running in a nearly northwest direction. The pitch is very heavy toward the south. These are probably the southern ends of the folds and uplifts which have brought up Charleston Peak. Together with the folding there was a great deal of minor faulting. A fault with a throw of a few hundred feet is seen about one-half mile west of Mule Spring. On the east side of Mule Spring is a steep escarpment

composed of Upper Carboniferous limestones overlying red shales. In this escarpment is shown a minor fault or a slight broken fold which appears to be recent and has directly displaced the surface.

On the west side of Mule Spring, at Mule Spring Mountain, the same formations are shown in a similar escarpment. Here the beds are thrown into minor folds and faults.

A great fault runs in a northerly to northwesterly direction directly through the center of the main Spring Mountain Range and through the minor ranges which are continous with it on the south (see map, Pl. I). This is shown 10 miles north of Wilson's ranch, where it runs nearly due north. It was also observed east of Mountain Spring (fig. 24), and at the east base of Olcott Peak (fig. 23), and was traced past Good Spring to the southeast. At Good Spring its course is north and south.

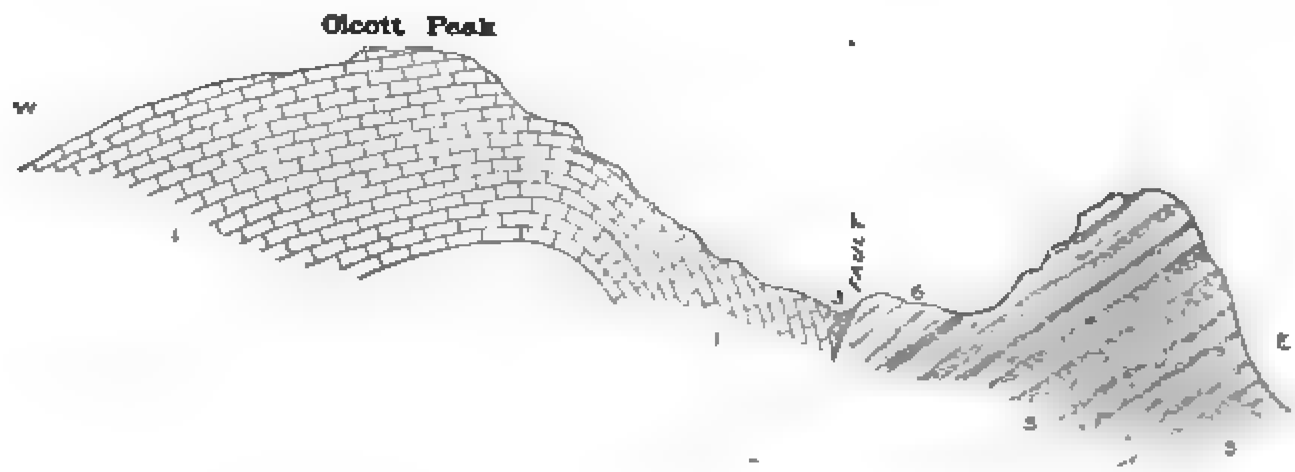

FIG. 23.—Section showing the great fault at Olcott Peak; after R. B. Rowe.

1. Lower Carboniferous limestones.
3. Upper Carboniferous limestones.
5. Mesozoic red beds.
6. Mesozoic heavy white sandstone.

Mountain Spring occupies the center of the important anticline which forms Olcott Peak or Potosi Mountain. East of Mountain Spring there is exposed the great fault. East of the fault is an erosion scarp (fig. 24).

Between Wilson's ranch and Red Spring, and about 10 miles north of Wilson's ranch, there is an overthrust fault, by which the Carboniferous limestone is thrust over the massive red Mesozoic sandstone. Three important faults are shown here—two running parallel and nearly north or west, the other (the great fault) running at right angles, or nearly north and south.

At Cottonwood Spring the apparent section is:

Jurassic.
Upper Carboniferous.
Red Beds.
Jurassic.
Upper Carboniferous.

This can only be explained by a fault. It is to be inferred that the fault is an overthrust. No direct evidence was seen.

About 1 mile south of Cottonwood Spring the Carboniferous rocks strike S. 63° W., and dip 30° NW.

About 6 miles east of Cottonwood Spring a great escarpment consists of Upper Carboniferous beds underlain by reddish shales and sandstones. Mr. Rowe's section indicates that the escarpment has been formed by the erosion of these softer beds.

In the valley east of the Cottonwood Spring escarpment there is probably a fault within the shale belt. This must be an overthrust fault along bedding planes, because everything appears to be conformable. Red beds of the Carboniferous overthrust on the red beds of the Mesozoic make the fault difficult to see. Two or three days' search failed to reveal any direct indication (fig. 24).

There is some minor faulting shown in the Upper Carboniferous strata about Cottonwood Spring, and some minor folding in the Jurassic east of the springs.

On the divide between Good Spring and Cottonwood Spring there appears to be some very sharp folding or faulting at right angles to the general trend of the great faults, and at right angles to the great fault running on the east side of the Charleston Range.

The great fault lying on the east side of the Spring Mountain Range may be followed easily northward from Good Spring to the divide between Good Spring and Cottonwood Spring, 12 miles. On the east side of the fault is heavy-bedded red sandstone and red shales. On the west is Middle or Lower Carboniferous and Upper Carboniferous

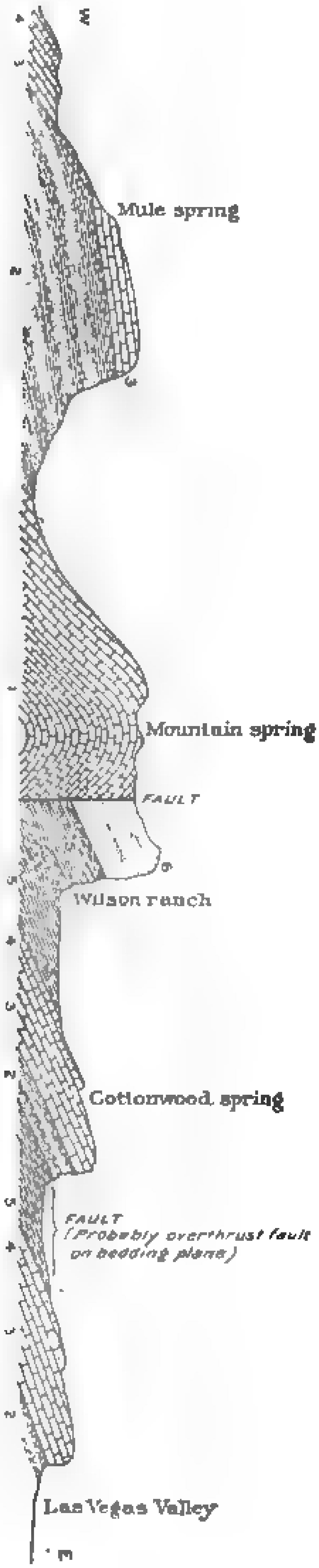

FIG. 24.—Cross section of southern end of Spring Mountain Range (east and west), showing the great fault several miles north of point represented in fig. 23; after R. B. Rowe.

1. Lower Carboniferous limestones.
2. Carboniferous red beds (shales and sandstones).
3. Upper Carboniferous limestones.
4. Jurassic limestone.
5. Mesozoic red beds.
6. Mesozoic heavy white sandstone.

wedged in the fault by the drag (fig. 23). The section given by Mr. Rowe shows an anticline overthrown to the east and faulted. The fold is cut deeply by canyons. Along its axis the rocks are much crushed and broken, and much minor faulting is visible in places. This great fault line was followed north toward Wilson's ranch. It changes its course from about 15° west of north, south of the summit, to 45° west of north, north of the summit.

About 3 miles north of Good Spring the Carboniferous is folded into a sharp anticline and syncline.

The general structure of the Bird Spring Mountains seems to be anticlinal, with a channel of erosion along the apex of the anticline. There is a fault along the east side of the range which brings the Lower Carboniferous against the red shales and sandstones of the Mesozoic. This fault runs northwest and southeast (see fig. 25). About 1½ miles north of Bird Springs there is another fault, which crosses the first one at an angle and brings the Lower and Upper Carboniferous together.

About 6 miles south of Good Spring the Lower Carboniferous is overthrust upon the Jurassic. The rocks are very much disturbed along the fault line.

About three-quarters of a mile south of the summit, between Good Spring and Wilson's ranch, there is a fault which brings the Upper Carboniferous above the Jurassic. The fault has a nearly due northwest course. About 3 miles southeast of the summit there is another fault, also running due west, which

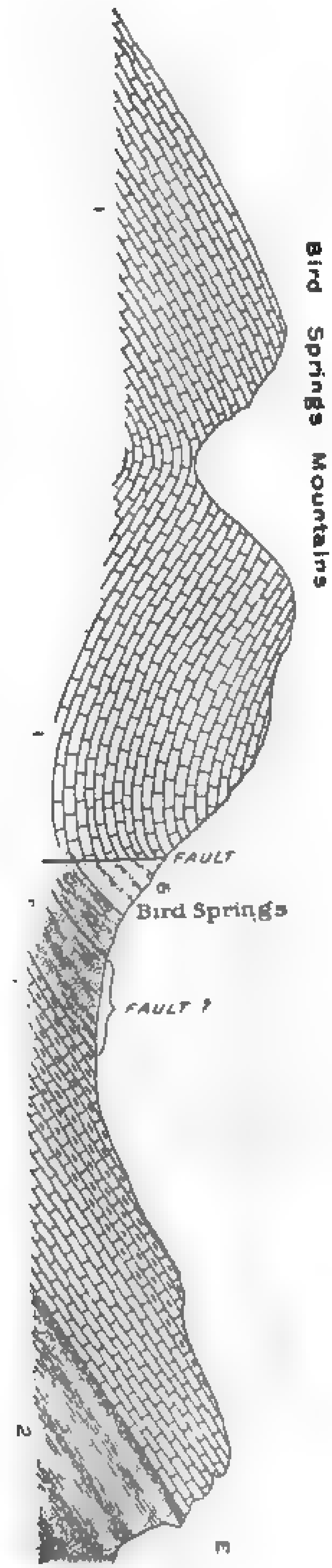

FIG. 25.—Cross section of Bird Spring Mountains (southern spur of Spring Mountain Range); after R. B. Rowe.
1. Lower Carboniferous limestones. 2. Carboniferous red beds (shales and sandstones). 3. Upper Carboniferous limestones. 4. Jurassic limestone. 5. Mesozoic red beds. 6. Mesozoic heavy white sandstone.

brings the Upper Carboniferous and Jurassic against the Lower Carboniferous. These faults are nearly normal to the direction of the main northwest-running faults. Minor folds shown at the summit seem to be at right angles, or nearly so, to the main folds running northwest.

About 6 or 7 miles west of Corn Creek, on the south side of the valley between Las Vegas Range and Spring Mountain Range, there is apparently a fault bringing the Cambrian against what is probably the Carboniferous.[a] The Cambrian comprises a number of parallel ridges running east and west. The strata dip north. Each of the ridges has a steep escarpment facing south. Possibly there is a series of faults running parallel to the strike.

Just south of Indian Spring, at the northern end of the range, the Upper Carboniferous limestones show considerable minor faulting and folding. Except where locally folded, the dip of these rocks is generally southwest. About one-half mile south of the spring, yellowish arenaceous limestone is brought by a fault against dark-blue cherty limestone. The rocks are much broken, also, by minor faults, which are hard to observe. An unconformity is shown in several places between the red shaly Carboniferous beds and the overlying Carboniferous limestone.

ORE DEPOSITS.

In the extreme southern part of the range is the old Potosi or Yellow Pine mining district. Here there are veins of argentiferous galena in the limestone.[b]

AREA SOUTH OF SPRING MOUNTAIN.

From Mr. Rowe's notebooks the following information is taken:

The range on the east side of State Line Pass, about 12 miles south of Good Spring, shows fossiliferous Carboniferous limestone on the west side. The limestone on the east side is probably also Carboniferous, but no fossils were found. The section made by Mr. Rowe seems to show faulting separating the two limestones. The beds dip throughout the whole section to the west.

Mr. H. W. Turner has kindly supplied the following note:

Locality on the boundary line between San Bernardino County, Nev., and Lincoln County, Nev., at State Line Pass, at about 6,000 feet elevation. Mr. Schuchert states that the collection which was made by F. C. Boyce contains two species—a *Chætetes*, which is usually identified as *C. milleporaceus* Edwards and Haime, and a *Productus* of the *P. cora* type. The horizon from which these fossils are derived is Carboniferous, and probably Upper Carboniferous.

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[a] This is very likely the same fault as described above by the writer (J. E. S.).

[b] Geol. Surv. California, Vol. I, p. 471.

The north end of the McCulloh Mountains is Carboniferous and seemed to be lithologically like the Carboniferous of the Bird Spring Mountains, consisting largely of light-gray arenaceous limestones.

KAWICH RANGE.

The Kawich Range forms the southern continuation of the Hot Creek Range, from which it is separated at its northern end only by a narrow transverse pass. From this point it extends due south about 60 miles, where its southern end runs out into the desert valley.

TOPOGRAPHY.

The range is high and is deeply eroded into bold, craggy mountains. On both sides the slope of the mountains is steep, especially on the west, where there are almost impassable cliffs. On the flanks of the range on both sides of the rugged backbone are smoother, mesa-like forms.

SEDIMENTARY ROCKS.

TERTIARY.

The only stratified rocks known in the Kawich Range are the rhyolitic tuffs and sandstones which occur in the pass between the Kawich and the Hot Creek mountains and which also mantle around the northern base of the Kawich Range. These strata are evidently the same as those described at Twin Springs, between the Pancake and the Reveille ranges. They are closely associated with Tertiary rhyolites.

IGNEOUS ROCKS.

The igneous rocks constitute the whole of the main range, so far as noted. The rough, deeply eroded central mass of the mountains is composed of biotite-rhyolite similar to the basal rhyolite of the Reveille Range. In these rhyolites, as in those of the Reveille Range, there is a pronounced north-south jointing or sheeting which is not found in the younger lavas. The dissected mesas found in a narrow belt at the base of the mountains are composed chiefly of more basic lavas, with some acid lavas. From the western side of the range, near its northern end, specimens of tordrillite and biotite-andesite were collected. In the pass between the Kawich and the Hot Creek mountains decomposed andesite was found.

At the northern end of the Kawich Range the rhyolite abuts against the Paleozoic strata of the Hot Creek Range in such a way as to show that the mountains of the Hot Creek Range were already eroded out of the limestones before the rhyolites were extruded.

RALSTON DESERT.

East of the Sierra Nevada there is a belt of mountain ranges which have a Paleozoic or old granitic core, which have considerable heights, and whose general trend is northwest and southeast, parallel with the face of the Sierras. In this belt the rocks show frequently compressed or even overthrown folds, yet have experienced vastly less compres-

sion than the intensely folded and sheared strata of the Sierra. East of these auxiliary ranges there is a belt which is comparatively free from Paleozoic or old granitic ranges. It has been covered in many places by late Tertiary or Pleistocene lavas, so as partly to conceal the fact that it is a broad depression, but nevertheless this character is still traceable and even well marked on a topographic map. This great belt runs northwest and southeast, parallel with the Sierra, and separates the region of northwest-trending ranges on the west from the north-south trending ranges on the east.

The Ralston Desert forms a portion of this. Northwest of the Ralston Desert the depression is continued by the lower end of Big Smoky Valley, by Sinkavata and Gabbs valleys, and farther north by the region of Carson and Pyramid lakes. Beyond this it appears to run up into Oregon.

On the south the Ralston Desert is separated from the Amargosa Desert by an irregular belt of late Tertiary volcanic mesas, through which Fortymile Canyon is cut. At the south end of the Amargosa Desert the open belt becomes narrow, but farther south passes into the Mohave Desert.

The Ralston Desert is bounded on the north and south by late Tertiary volcanic mesas, which, indeed, are found throughout its extent, so that these boundaries are rather arbitrarily taken. On the west the desert ends at the chiefly Paleozoic Silver Peak and Grapevine ranges, while to the east it is limited chiefly by the rugged Kawich Range, which appears to be principally rhyolite.

In general the desert consists of an irregular but nearly level sandy plain, broken by bunches of low mesas or slightly eroded volcanic mountains. Stonewall Mountain, which lies about 30 miles east from Lida, is an exception to this topography, being a high, rugged group, reaching probably 9,000 feet in altitude, or 4,000 feet above the desert at its base. The northern side of this mountain is a steep cliff escarpment, probably 1,000 or 1,200 feet high, and is perhaps a simple fault-scarp. (See Pl. VII, *A*.)

IGNEOUS ROCKS.

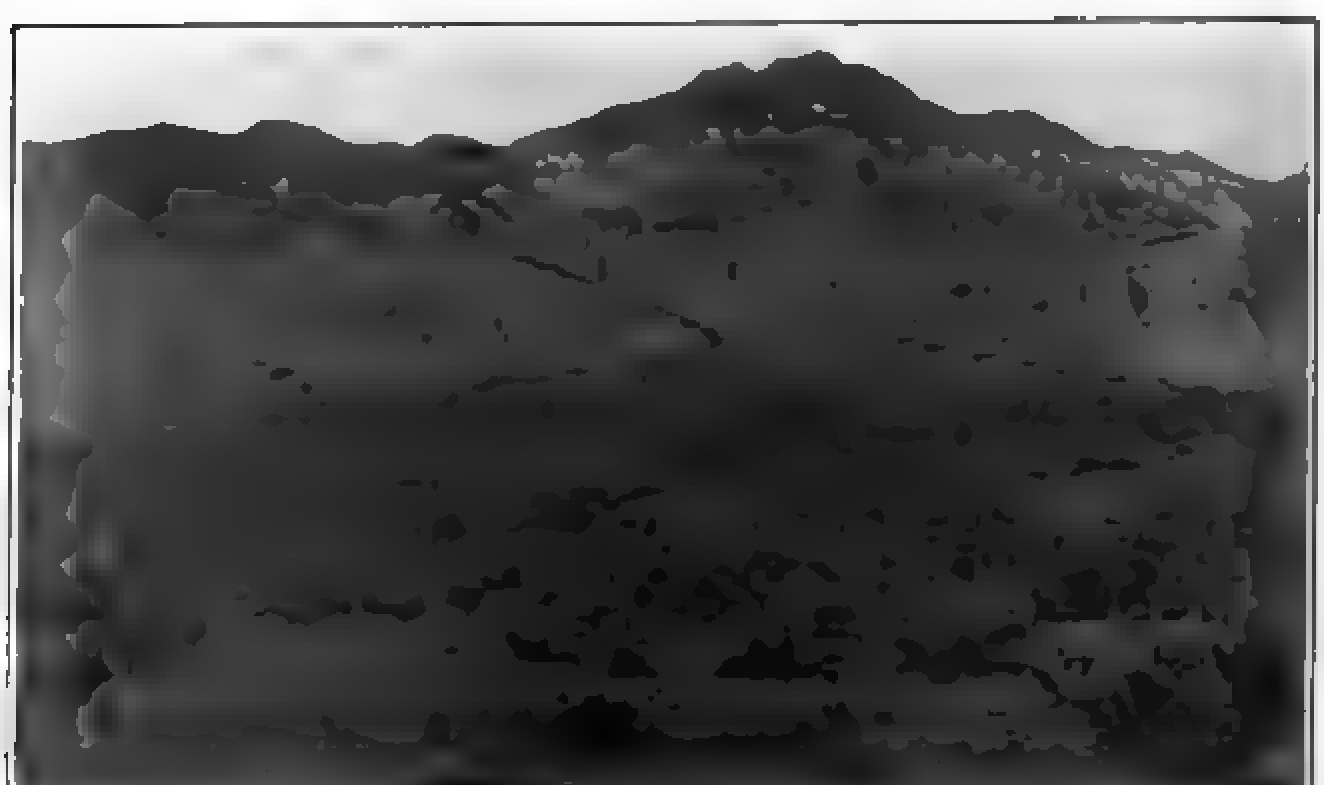
RHYOLITES.

Stonewall Mountain is entirely made up of rhyolite, and has been so deeply eroded that it can not be of very recent age. This rock is probably the same as the rugged rhyolite core of the Kawich Range. Northeast of Stonewall the low mountains in which Cactus Corral is situated are composed of rhyolite and tordrillite, also considerably eroded and probably belonging to the same period.

Most of the hills in the desert, however, show comparatively slight erosion. They represent thin flows, which have been very fluid and so have run comparatively long distances from the vent, at a very slight angle of descent. So the edges are thin-benched mesas, while the thicker, inner parts are irregular hills. While these mesas are

A. NORTH SCARP OF STONEWALL MOUNTAIN, RALSTON DESERT.

A fault scarp (?)



B. PYRAMID PEAK, GRAPEVINE RANGE, FROM THE HEAD OF FURNACE CREEK.

evidently younger than the deeply eroded rugged rhyolite of Stonewall Mountain, yet they seem to be, in part at least, older than certain horizontally stratified rhyolitic clays which will presently be described as occupying a large portion of the desert between the volcanic hills and underlying the Pleistocene sands. Within these stratified clays, and sometimes capping them, are also beds of rhyolite, very fine grained and often glassy. This is evidently the youngest of all the rhyolites, and we may infer that the rhyolitic eruptions lasted a long time, beginning with those of Stonewall Mountain and ending with the slaggy flows last mentioned.

BASALT.

The latest lava of the desert is a flow of slaggy olivine-basalt, lying at the base of Jackson Mountain, which is just east of Lida. This is not only younger than the youngest rhyolite, but is apparently younger than the erosion of this and the underlying sediments to form the buttes, of which Jackson Mountain is one.

SEDIMENTARY ROCKS.

TERTIARY.

The main portion of Jackson Mountain consists of several hundred feet of hardened, horizontal sands and clays, containing irregular fragments of rhyolite. The base of the mountain is at an elevation of 5,100 feet, so that the uppermost sediments are at least 6,000 feet.

In the valley between Stonewall Springs and Cactus Corral there is also found green, hardened, rhyolite ash containing harder fragments. It is evenly and horizontally stratified and is overlain on the edges by the Pleistocene gulch dumps, or wash, which sometimes extend to the middle of the valley. The ash is eroded into hummocks.

This thick series of volcanic sands and clays was probably deposited in a body of standing water and represents a lake contemporary with the later rhyolitic eruption. As seen from the sediments of Jackson Mountain, the lake must have been at least 1,000 feet deep on the desert.

PLEISTOCENE.

Along the slopes of all the mountains, especially of Stonewall Mountain, are great wash slopes and gulch dumps fringing the scarp. This material, flowing down into the valley, overlies the Tertiary lake deposits. In the bottoms of the valleys are broad, bare mud flats or playas, evidently quite recent and contemporaneous with the gulch dumps. They seem to be simply sinks, where at intervals water collects and speedily evaporates. They do not represent the residuum of evaporated Pleistocene lakes of which, moreover, there is no other evidence.

LONE MOUNTAIN.

For the following slight description of Lone Mountain the writer is indebted to Mr. Turner, since he himself saw the mountain only from a distance. The mountain really forms the northern end of the

Montezuma Ridge of the Silver Peak Range, but on account of its exceptional height and prominence has been given a separate name.

IGNEOUS ROCKS.

The main part of Lone Mountain consists of craggy, light-colored, massive granitic rock.

SEDIMENTARY ROCKS.

South of the granitic area the central portion consists of Cambrian limestones To the east of this Cambrian belt is a belt of Silurian limestones, as determined by Mr. Turner. Along the west flanks of the mountain the upturned beds of the Esmeralda formation (earlier Tertiary) occur.

SILVER PEAK RANGE.

The Silver Peak Range is short and somewhat irregular in form. It lies immediately east of the northern end of the White Mountain Range, and like this range has a general northwest-southeast trend. On the north the range is separated by a low pass from the Monte Cristo Mountains, while on the south it runs into the northern end of the Grapevine and Panamint ranges. From near the southern end of the range a spur runs off to the north, forming the eastern boundary of Clayton Valley, which lies between it and the main range.

The Silver Peak Range was studied by Mr. H. W. Turner during the summer of 1899, and the mapping of the formations over most of the range has been kindly furnished by him to the writer. Most of the following notes on the geology, designed to explain the map, are also due to him. Mr. F. B. Weeks, of the Geological Survey, also spent some time during the same season in the Silver Peak region, chiefly for the purpose of collecting fossils, and the present writer passed through it on his way from Columbus to Lida.

The range is mostly made up of folded Paleozoic rocks, together with intrusive granite and a large amount of volcanic material.

SEDIMENTARY ROCKS.

CAMBRIAN.

Fossils obtained by Mr. J. E. Clayton, as early as 1866, at Silver Peak, and first regarded as Silurian or Devonian, were shown by Mr. Walcott[a] to be Middle Cambrian. The studies of Mr. Turner have furnished many details concerning these Cambrian rocks, which occupy considerable portions of the range. In some of the Cambrian limestones masses of the same corals occur as in the White Mountains to the west, so that Mr. Walcott regarded the two occurrences as essentially forming part of a single reef.[b]

The chief area of Cambrian is north of Silver Peak, where it is capped by volcanic rocks in many places. The buttes in Clayton

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[a] Bull. U. S. Geol. Survey No. 30, p. 38.

[b] Am. Jour. Sci., 3d series, Vol. XLIX, p. 144.

Valley are also largely Cambrian. The section consists of comparatively massive limestones and quartzites.

Along the road leading from Silver Peak by way of Barrel Springs to the southern end of the range at Lida, the rocks are chiefly Cambrian limestones. At Lida the writer collected fossils referred by Mr. Walcott to the Lower Cambrian.

SILURIAN.

Mr. Turner found overlying the Cambrian limestones other limestones containing occasional graptolites, which he therefore refers to the Silurian. An area of these Silurian rocks occurs north of Benderes Pass, while a belt of the same rocks occurs encircling a granitic area north of Palmetto. Silurian rocks are also found on the southwestern edge of the branch mountain ridge above described, which may be called the "Montezuma Ridge" from the mining camp which is situated on it.

EARLY TERTIARY.

On the flanks of this range Mr. Turner has described sediments to which he gives the name of the Esmeralda formation.[a] These deposits consist of sandstones, shales, volcanic tuffs, breccias, and conglomerates, and great thicknesses of lacustral marls. Coal beds and plant remains occur; also fossil shells and fish bones. From this fossil evidence the age of the beds is broadly determined as late Eocene or early Miocene. The beds are nearly always folded, dipping from 10° to 40°, but the entire thickness may be several thousand feet.

PLIOCENE.

A butte in Clayton Valley, northeast from Silver Peak, which is capped by olivine-basalt, is chiefly made up of horizontally stratified, partially consolidated, green volcanic ash and tuff, with pebbles of dark lava. The stratified beds are undoubtedly water-laid and are probably unconformable with the folded Tertiary series just described, which occurs in patches all over the valley to the north of here. In general appearance the beds are like the Pliocene sediments which have such a broad distribution north of here, such, for example, as occur on the pass between the Candelaria Mountains and the Pilot Mountains. They are also similar to the latter occurrence in being capped by olivine-basalt and not being folded.

Going south from Silver Peak to Barrel Springs, the slopes of the mountains consist of rolled gravels whose pebbles are derived from most of the rocks around, including the lavas. These extend back eastward to the hills of the Montezuma Ridge, which are made up partly of volcanic rock. In the canyon below Barrel Springs the stratified gravels and sands, containing rhyolite pebbles, are found to lie against the eroded edge of a deposit of white volcanic ash and pumice apparently water-laid, and this ash lies against the eroded

[a] Am. Geol., Vol. XXV, p. 168.

edge of the slightly dipping Cambrian limestone. These gravels and sands seem to be the same as those in the butte described above.

In the outlying hills of the southern part of the range just east of Lida is a series of hardened, stratified, greenish clays and sands containing fragments of rhyolite. These clays have sometimes been eroded to form buttes, especially where capped by lava. They are horizontally stratified and undisturbed, and are younger than the flow of olivine-basalt which sometimes mantles around the base of the buttes.

The deposits in these different localities may be provisionally correlated with the other sediments which have already been ascribed to the Pliocene-Pleistocene Shoshone Lake.

IGNEOUS ROCKS.

In the Silver Peak region the igneous rocks are abundant and varied.

GRANITES.

Granites occupy considerable areas, and field evidence shows that they are intrusive into the Paleozoic sediments, but not into the Tertiary rocks.

VOLCANIC ROCKS.

The volcanic history of the region is of considerable complexity and interest. Mr. Turner, who has made a study of this, has kindly supplied the writer with the information that the succession of lavas in this district has been, in general, (1) rhyolites, (2) andesites, and (3) basalts.

ORE DEPOSITS.

At Silver Peak there are rich silver and gold mines. The Cambrian limestones are cut by pegmatitic granitic rock, which changes to pegmatite and quartz veins. The ores appear to be, partly at least, connected with these intrusions.

Numerous other localities are known where mineralization has occurred. At Barrel Springs the limestone is decomposed and stained along a vertical zone 10 yards wide with iron and copper. The honeycombed and cavernous appearance of the rocks shows that they have been the channel for ascending springs, to which the mineralization is undoubtedly due.

At Lida the writer noticed an auriferous quartz vein 5 or 6 feet wide, occurring along the entire contact of a 20-foot-wide nearly vertical dike of quartz-monzonite-porphyry which cuts the nearly horizontal Lower Cambrian limestones. This dike is evidently a phase of the general granitic intrusion and the quartz vein is an accompaniment.

CHAPTER IV.

GREAT BASIN RANGES OF CALIFORNIA, NORTH OF MOHAVE DESERT.

GRAPEVINE AND FUNERAL RANGES.

The Grapevine and Funeral ranges are practically parts of a single mountain chain, which is the easternmost of the important chains belonging to the Sierra Nevada auxiliary belt. This chain faces the Amargosa and the Ralston deserts on the east, and has a northwest-southeast trend. The Grapevine Range is continued on the north by the Silver Peak Range, from which it is separated only by a comparatively narrow transverse valley.

That portion of the range which lies immediately north of Furnace Creek has been sometimes called the Amargosa Range; but in the present description all of the mountains from Furnace Creek northward will be included under the single term Grapevine Range, while those south of Furnace Creek will be described as the Funeral Mountains. To this southern portion of the range the name Amargosa has also been applied, and to certain parts of it the name Black Mountains; but these will here be omitted.

The Funeral Mountains have a trend somewhat different from that of the Grapevine Range, being more nearly north and south. This change is accompanied by a similar change in the trend of the Panamint Range, which lies next west.

The Grapevine Range is not of great width, but is high and narrow, with wild scenery (Pl. VII, *B*). The Funeral Mountains are lower, and have a striking air of desolation, due to the lack of vegetation and the dark, gloomy colors of the rocks. Both the Grapevine and Funeral ranges are cut by deep canyons which sometimes extend quite through the range, a phenomenon frequent in the Great Basin ranges.

At Furnace Creek the Grapevine Range fronts the Funeral Range with a south-facing scarp, so steep as to be almost inaccessible and about 4,000 or 5,000 feet in height. At the base of this scarp the drainage from it has cut a channel parallel with its front, which forms that branch of Furnace Creek along which the road runs across the mountains.

Both the Grapevine and the Funeral mountains present steep sides to Death Valley, which are bolder than the western side of the valley.

SEDIMENTARY ROCKS.

Mr. George G. Davis has kindly sent the writer samples of the chief rocks at Gold Mountain, which appear to be a grayish, rather coarse-grained quartzite and a dark blue-gray slaty limestone of ancient appearance. These rocks may perhaps be Cambrian or Silurian.

At Boundary Canyon Mr. Gilbert found limestones with imperfect fossils, which, with the stratigraphic data, serve to connect the rocks with the Cambrian beds observed farther east.[a]

At the extreme southern end of the range, at Saratoga Springs, Mr. Gilbert[b] has noted the following section (from top to bottom):

Section at Saratoga Springs.

	Feet.
1. Gray clay slate	600
2. Yellow slate, with beds of shaly limestone	800
3. Bedded and shaly limestone, banded in purple, yellow, and brown	350
4. Crystalline limestone	40
5. Dark-brown quartzose and argillaceous conglomerate	140
6. Crystalline limestone	85
7. Green shale	20
8. Massive hornblende rock, black to green	120
Total	2,155

According to Mr. M. R. Campbell,[c] the rocks composing the southern end of the Funeral Range at Saratoga Springs are limestone, shale, and quartzite, presumably of pre-Cambrian age and containing no fossils. They strike north and south, and dip about 50° E. No Tertiary rocks were seen in the southern end of the range from Saratoga Springs, while strata resembling those exposed at Saratoga Springs could be traced northward for several miles into the high summits.

SILURIAN.

At Furnace Creek Valley the writer observed bowlders of pure white, vitreous quartzite extending down from Pyramid Peak, although the main mass of the mountain is limestone. This quartzite resembles the Silurian Eureka quartzite, so persistent in Nevada, and the relation of these beds to those overlying, which are probably Devonian and Carboniferous, makes it probable that in Pyramid Peak and west of it the strata are largely Silurian. The writer has been informed by Mr. F. B. Weeks, of the United States Geological Survey, that at Grapevine Peak limestones carrying Lower Silurian fossils (probably corresponding to the Pogonip formation of Eureka) occur, and he regards these Silurian rocks as probably continuous southward to Pyramid Peak.

DEVONIAN.

In the mountains east of Pyramid Peak a great series of easterly dipping limestones are exposed, in which badly preserved fossils

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, pp. 33, 169, 181.
[b] Ibid., p. 170.
[c] Bull. U. S. Geological Survey No. 200, 1902, p. 14.

resembling those found in the rocks of the ranges just east of here were observed. In the Kingston Range Devonian fossils were collected from similar rocks, and from the great thickness of the section exposed in the Grapevine Range at this point it is likely that both the Devonian and the Carboniferous may be represented here.

TERTIARY.

In the eastern part of the range, where the road crosses from the Amargosa Valley into Furnace Creek, there is found a great amount of conglomerate, forming high hills. These conglomerates are very coarse and contain rounded pebbles and bowlders of all sizes, made up of reddish and white quartzite and black and gray limestones bearing the badly preserved Paleozoic fossils above mentioned. The conglomerate is as hard and firm as the rocks from which it is derived. It is water-laid and well stratified, and evidently a shore formation. The whole thickness exposed is estimated at 4,000 feet. It is sharply folded, together with the limestones from which it is derived, but it abuts abruptly against these limestones on the west.

The irregularity of the contact between conglomerate and limestone denotes a great erosion interval, yet no unconformity of attitude is apparent.

This conglomerate seems to fringe the north edge of the bold Paleozoic scarp of the Grapevine Mountains across the greater portion of the range. It is found at various points. A little west of Pyramid Peak conglomerate occurs, interbedded with and running laterally into a hard limestone, which has all the appearance of being calcareous tufa. A specimen examined microscopically bears out this idea and shows that the rock is probably a chemical precipitate. It is like a rock found in crossing the Panamint Range from Death Valley to Windy Gap, and also like one from the Esmeralda formation, between the Candelaria Mountains and the Pilot Range.

Besides these rocks there occur, as parts of the same series, semiconsolidated gravels, with clays partially hardened to slaty shales, limy clays partially consolidated to argillaceous secondary limestones, and sands partially hardened to cherty and limy sandstones, all interbedded. All these, including the conglomerate and the limestone tufa, have a general light-yellow, often greenish color, characteristic of the series.

This sedimentary series makes up the greater portion of the Funeral Range. Along Furnace Creek Valley and on both sides of it the mountains consist chiefly of yellow-green strata capped by basalt. The lava seems to occur interbedded with the sedimentaries, as well as overlying them. The series is here consolidated into a hard clay rock, with occasional thin sandstone, and the general yellow-green color is changed in places to reddish, yellowish, and pinkish. The rocks are often gypsiferous and contain abundant grass remains,

which are, however, indeterminable. From the yellow-green Tertiary series in the hills just east of the mouth of Furnace Creek there has been taken much borax, which occurs as borate of lime in beds in the strata. Superintendent Roach, of the borax works at Daggett, says that from one hill here—Mount Blanco—200 tons of borax a day could be easily shipped.

On the eastern side of Death Valley, southward from Furnace Creek, the upturned yellow-green Tertiaries, with some few intercalated sheets of lava, constitute the mountains. Beneath some of these sheets the clays are baked to a red, natural brick. The lavas seem to occur chiefly at the top of the yellow-green series, or at a still higher horizon, for the great mass of beds exposed in the lower portion of Furnace Creek contains no lava sheets; yet in these beds occur occasionally lava bowlders and pebbles, so that we conclude that the period was one of continual volcanic activity. From fragments of lava picked up at the base of the mountains and from observations at a distance the lower lavas seem to be not so basic as the upper ones, which are chiefly olivine-basalt. A single specimen of biotite-andesite was all that was collected to represent these more siliceous volcanics.

Near the summit of the pass, just east of Furnace Creek, there come in above the yellow-green Tertiary series softer, dark-brown, honeycombed conglomerates, recalling the similar rocks of Meadow Valley Canyon. Thin sheets of basalt are interbedded with the conglomerates, but the great sheets lie on top. Patches of this same upper conglomerate series were elsewhere observed, and at one place its contact with the underlying yellow-green series appeared slightly discordant. The conglomerate contains pebbles and bowlders which are chiefly of lava and must have been derived from the sheets of basalt which were periodically poured out during the deposition of the beds.

A rough estimate of the thickness of this whole series of slightly consolidated beds and volcanics puts it at not less than 4,000 feet, and the nature of the sediments shows that they must have been deposited in standing water. The presence in some of the beds of gypsum, borax, and calcareous tufa shows that at some periods the waters in which the sediments were deposited were evaporated. They were, therefore, those of an inclosed lake, which was probably of great dimensions. It is likely that a large portion of the beds were deposited in fresh water at a period different from that in which the chemical precipitates were laid down.

The borax in these beds is probably contemporaneous with the borax deposits in similar folded Tertiaries at Daggett and elsewhere in the Mojave Desert. Between these two localities, moreover, the strata, so far as known, appear to be roughly continuous. The strata of Mojave Desert are exposed on a grand scale at Cajon Pass, where they contain beds of black lignite.

Northward from Furnace Creek, at Silver Peak, are found beds of the Esmeralda formation, which are entirely similar in nearly every respect to those at Furnace Creek. Moreover, the fossils found in the Esmeralda beds indicate a nearly similar age to that indicated by fossils found in the Tertiary strata of the Mojave Desert, just west of Cajon Pass.

The upper part of the Furnace Creek beds is identical in appearance with certain semi-indurated and slightly folded conglomerates and sandstones found in Meadow Valley Canyon, which have been referred to the Pliocene.[a]

PLEISTOCENE.

At the lower end of Furnace Creek the steeply dipping Upper Tertiary gravels are overlain directly and unconformably by horizontal gravels, which are partly consolidated and form bluffs 15 feet high.

These are the same gravels as were noted on the eastern flanks of the Panamint Range, on the road crossing to Windy Gap, the beds here having the same appearance and position. Their perfect horizontality indicates that they are perhaps the deposits of a post-Tertiary lake. This lake was a few hundred feet deep, as measured by the highest of these sediments.

It therefore appears probable that the Furnace Creek beds represent nearly the whole of the Tertiary period, from the Eocene through the Pliocene. It is possible also that the uppermost lavas belong in the Pleistocene, for they are fresh olivine-basalt, like that which is known to have been extruded throughout the Great Basin region during the Pleistocene.[b]

A considerable portion of the area of greatest depression is occupied by a great brown desert. This has the appearance of a newly plowed field in color and form, and appears soft. On examination the surface is found to consist entirely of hard salt, rendered brown by a mixture of soil. This deposit is probably the result of the evaporation of the Pleistocene lake.

This lake was fed by the Amargosa River. The writer has been informed by those who are familiar with this region that occasionally the Amargosa River has been seen to be 200 feet wide at the southern end of Death Valley, although generally it is dry on the surface as far up as Ash Meadows. Along this dry course it flows underground, as is shown by the fact that water may generally be found by digging a few feet below the surface. In Death Valley, also, water can be found in many places by digging, so the dregs of the lake may be said to still exist.

[a] See description of Meadow Valley Canyon, Meadow Valley Range, Mormon Range, and Virgin Range.

[b] See J. E. Spurr, Succession and relation of lavas in the Great Basin region: Jour. Geol., Vol. VIII, p. 636.

IGNEOUS ROCKS.

GRANULAR ROCKS.

Granitic rocks are said to occur at Gold Mountain, at the northern end of the range, where the gold ores are connected with them.[a]

OLIVINE-BASALT AT FURNACE CREEK.

The Funeral Mountains are capped by heavy flows of pyroxene-olivine-basalt, which seems to have been slightly involved in the latter part of the folding which affected the underlying Tertiaries. The rock is black and slaggy and is identical in appearance and composition with the Pleistocene olivine-basalts found frequently in Nevada.[b]

Besides capping the Tertiary sediments, the basalt occurs in sheets which are, in part at least, certainly contemporaneous with the upper portion of the sediments, especially the conglomerate series. One basalt sheet was noted as metamorphosing the underlying conglomerates, but not the upper ones, and is therefore probably a flow and not an intruded sill. Moreover, the pebbles and bowlders in the upper conglomerate series are largely of the same basalt.

ANDESITE AT FURNACE CREEK.

Beneath the basalt sheets there is a certain amount of less basic volcanic material in the beds. This was not carefully investigated, but a single specimen showed that biotite-andesite is represented.

VOLCANICS NORTH OF FURNACE CREEK.

North of Furnace Creek the whole northeastern side of the Grapevine Range is overlapped by the sea of lava which occurs over most of the Ralston and Amargosa deserts, except where obscured by Tertiary or Pleistocene detrital accumulations. At the north end of the range these volcanics may connect with the volcanic area just north of Gold Mountain, which there extends to the western side of the range and is probably connected with the lavas at the northern end of the Panamint Range.

Mr. Gilbert[c] notes that rhyolite occurs a few miles north of Boundary Canyon, flanking the range both on its eastern and its western side.

STRUCTURE.

Mr. Gilbert[d] has drawn a section of the Grapevine Range at Boundary Canyon. This section shows essentially a main anticlinal fold, slightly overthrown to the west, with an auxiliary, broad anticline

[a] Wheeler Survey Explorations in Nevada and Arizona, War Department, 1871, p. 47.
[b] J. E. Spurr, Jour. Geol., Vol. VIII, p. 636.
[c] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 33.
[d] Ibid., p. 33.

forming the slopes of the range toward Death Valley, and a syncline between the two. These folds are much broken up by faults, which, as Mr. Gilbert notes, are not only longitudinal, but transverse.[a]

In crossing the mountains at the junction of the Grapevine and Funeral ranges, on the road leading to Furnace Creek, a good structure section was obtained. The south-facing scarp of the Grapevine Mountains shows a central chief anticline, with a very great thickness of uniformly easterly-dipping beds on the east limb. West from this central anticline, whose axis is immediately west of Pyramid Peak, there is a second anticline, also with steep dips, in the mountains immediately above Death Valley, and between the two anticlines is a slight syncline. On the south side of the pass, in the lower Funeral Mountains, it seemed to the writer that there is about the same structure, although the dips appear to be decidedly less. No faults were noted in this section, though they very likely exist.

The folds at Furnace Creek are probably continuous with those shown in Mr. Gilbert's section. As the writer looked along the face of the Grapevine Mountains, northward from Furnace Creek, he thought to be able to trace the western anticline at least as far as Boundary Canyon.

The Tertiary beds of the Funeral Mountains have therefore been folded together with the Paleozoics of the Grapevine Range. Yet the Paleozoic limestones appear to have in general steeper dips than the Tertiary strata. Nevertheless, the chief folding has come about since the deposition of the Tertiary. Not only the lower Tertiary beds, but also the upper conglomerates are folded, and even to a certain extent the interbedded and overlying olivine-basalt, which is of fresh appearance and may be in part as young as Pleistocene. Certainly, therefore, the upheaval of the Funeral Mountains and the present Grapevine Range has been very recent indeed.

This is illustrated in the Funeral Range, which, as viewed by the writer, seemed to consist near its northern end of two anticlinal ridges with a synclinal valley between. This synclinal valley is occupied by Furnace Creek, which follows the folding in all its bendings. The northwesterly course of the lower portion of Furnace Creek is caused by a corresponding bend in the synclinal trough. This deflection of the Furnace Creek syncline appears not to be continuous into the Paleozoic strata just north of here, and it is very likely due to the differential folding of the Tertiary strata against the hard Paleozoic buttress. In the summit of the pass above Furnace Creek, this folding against the Paleozoic cliff is well shown by a sharp local anticline in the Tertiary beds, the north limb of which dips from 20 degrees to 45 degrees toward the Paleozoic wall, which does not take part in the

[a] Mr. F. B. Weeks, of the U. S. Geological Survey, found in 1900 that at Grapevine Peak the main range was decidedly synclinal in structure, the axis of the fold in general transverse to the trend of the range.

flexure. This fold, however, is of slight width, the dip reversing and flattening a hundred yards south. (See Pl. VIII, A.)

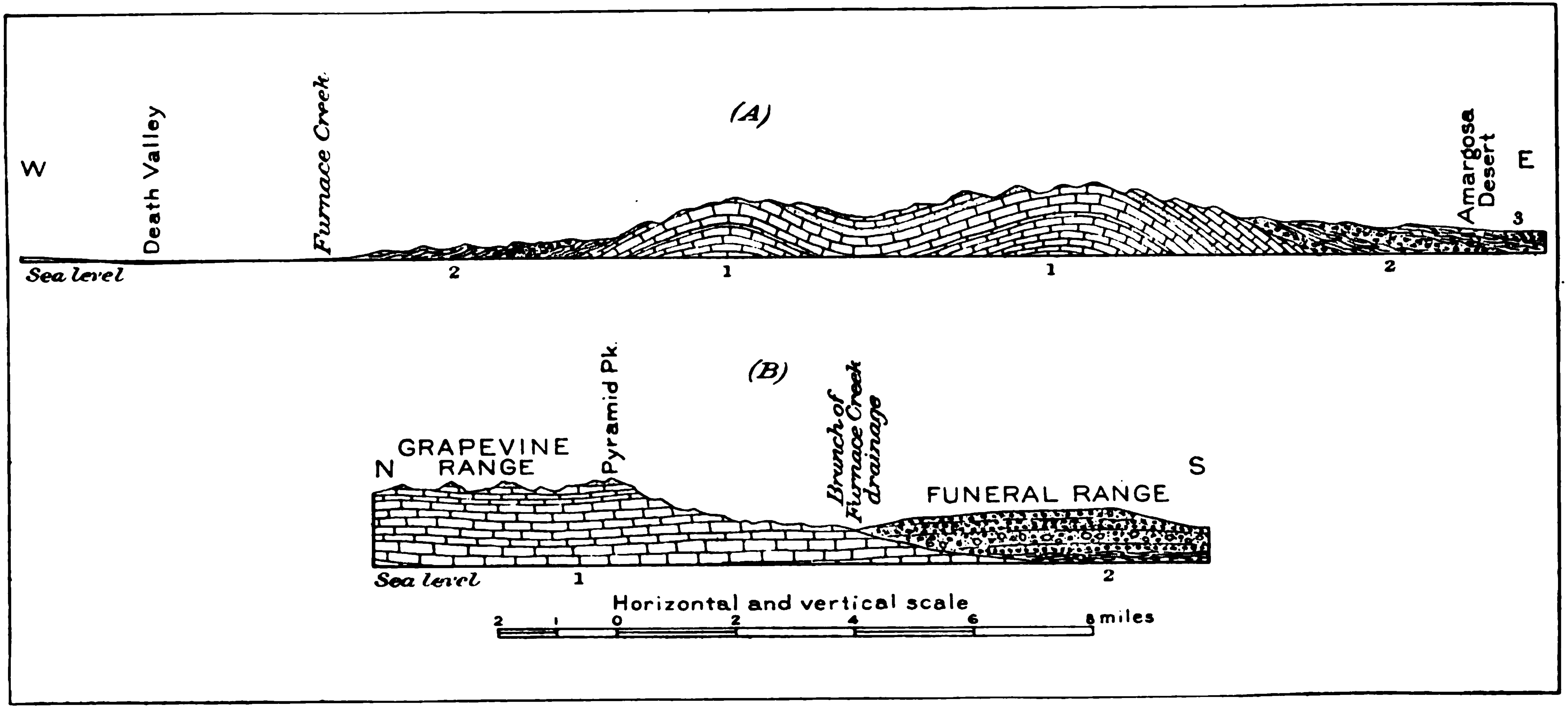
RÉSUMÉ.

The succession of events in the Grapevine and Funeral ranges and in the region of Death Valley is, then, about as follows:

1. Deposition of a thick, conformable, Paleozoic series.
2. Elevation to a land mass, without marked folding.
3. The formation of sharp, lofty mountains, with deep valleys.
4. The deposition of the thick Tertiary series. This took place, in part at least, in a great lake or inland sea. In this lake were deposited near the shores conglomerates and breccias derived from the Paleozoic rocks; in the other portions were formed silts mixed occasionally with gravels. During the deposition of this series, especially the later portion, there was volcanic activity, and sheets of lava were poured into the lake, thus becoming intercalated with the sedimentary beds.
5. The lake, probably generally fresh, was at certain times reduced and evaporated, so that beds containing salt, borax, silica, and lime were chemically precipitated and mingled with the detrital silts.
6. The volcanics changed to olivine-basalt. These lavas are associated with well-stratified sediments, such as might have been formed in a lake, but accurate data bearing on this point are lacking. The sediments may possibly be the result of stream action. They consist of brown and red conglomerates, which overlie the yellow-green lake beds, and are separated from them by some slight movement and perhaps an erosion gap.
7. Final flows of olivine-basalt.
8. Probably beginning before the deposition of the Tertiary, but not becoming very important until during and after the close of this period, came a disturbance, leading to rapid folding. The crust was bent, and perhaps broken, forming hills and valleys. Death Valley was created.
9. The mountains were eroded, producing minor irregular forms. The climate being slightly moister than now, a shallow lake a few hundred feet deep was formed in the bottom of Death Valley. This soon became charged with salt, borax, etc., derived chiefly from the leaching of the earlier lake beds, now become mountains. At this period the late Pleistocene shore gravels were formed.
10. The climate becoming drier, the lake evaporated, leaving a salt desert. Since that time there has been only a slight incision of the lake shore conglomerate by the drainage from the mountains to the dry valley.

AMARGOSA VALLEY.

The Amargosa Valley lies between the Kingston and Funeral ranges. The following notes are from Mr. R. B. Rowe's notebooks, except where credited to Mr. Campbell.



SKETCH STRUCTURE SECTIONS OF GRAPEVINE RANGE AT FURNACE CREEK.

A. Sketch cross section of the southern end of the Grapevine Range at Furnace Creek.
B. Sketch longitudinal section from the southern end of the Grapevine Range southward across Furnace Creek.

1. Paleozoic limestone, probably Silurian, Devonian, and Carboniferous.
2. Tertiary marls, arkoses, tuffs, and conglomerates, with intercalated lava sheets.
3. Pleistocene valley alluvium.

METAMORPHIC ROCKS.

Metamorphic rocks are exposed about a mile below the China ranch.

SEDIMENTARY ROCKS

TERTIARY.

Overlying the metamorphic rocks at the point mentioned above are Tertiary deposits. These Tertiary lakes were dry part of the time, or receded to a great extent and then swelled out again, for talus and lake deposits alternate with each other in the lower Amargosa. At China ranch the Amargosa River cuts through the Tertiary beds to a depth of 200 or 300 feet.

Mr. M. R. Campbell[a] has indicated on a map two areas of Tertiary lake beds near Amargosa Valley, one around Resting Springs and the other south of Ash Meadow.

STRUCTURE.

At China ranch the Tertiaries have been uplifted so that they dip at a high angle. The structure seems to be monoclinal. There is also some faulting in the Tertiary beds. Above China ranch the late talus deposits overlying the Tertiary are tilted up to a high angle, together with the Tertiary rocks.

For a distance of 3 miles, near China ranch, the Amargosa River has recently cut down about 20 feet into an old river deposit or wash. For a distance of about 1 mile it is beginning to cut down 4 or 5 feet farther. This is shown by waterfalls in the talus. This local downcutting seems to indicate recent movement.

Mr. M. R. Campbell[b] states that the Tertiary beds in this valley bear evidence of considerable crustal movement since their deposition. The eastern margin that rests against the foot of the Kingston Range is 800 feet higher than the uppermost beds of the same series at the foot of Funeral Mountain. This indicates a depression toward the west, in the direction of Death Valley. It seems possible that the change was due to the sinking of Death Valley to its present position below sea level.

KINGSTON RANGE.

The Kingston Range lies between Pahrump Valley and the valley of Amargosa River. The California-Nevada line passes along its eastern base. The range has a northwest-southeast trend and is 50 or 60 miles in length. At its northern end it is separated by a short valley, called Stuart Valley, from the mountains which lie directly north of Pahrump Valley, and which form an irregular group affording a partial connection between the Spring Mountain Range and the Kingston Range. This group will be described together with the Kingston Range.

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[a] Bulletin U. S. Geol. Survey No. 200. [b] Ibid., pp. 14, 15.

The Kingston Range generally has steep fronts, especially along the main eastern side, where it faces Pahrump Valley.

SEDIMENTARY ROCKS

CAMBRIAN.

Mr. R. B. Rowe, in 1900–1901, discovered and described Cambrian in the Kingston Range. The following information has been taken from his notebooks:

The greater part of the Kingston Range is made up of Cambrian strata. On the road from the post-office at Sandy to Kingston Peak there are sandstones and limestones, with metamorphosed gray schists cut by dikes.

Kingston Mountain consists of a central core of granite, which is topped on the north and northeast by a fine-grained white quartzite with reddish bands. The succession at Kingston Peak, near Horse Spring, from the bottom up, is as follows:

Section at Kingston Peak.

1. White, gray, or red quartzites.
2. Red, gray, and blue slates, and heavy beds of quartzite.
3. Dark blue, much altered limestone.
4. Light gray, arenaceous limestone, much altered, with crystallized calcite in its crevices and interspaces.
5. White and brownish quartzite, with conglomerate at the bottom. This sometimes alternates with the red, gray, and blue slates.

In some places the white quartzite at the base seems to run into a gray gneiss.

On the road between Manse and Resting Springs, through the pass going to Tecopa, there is an excellent section of the mountains east of Resting Springs. The Cambrian seems to be repeated at this point, probably by a fault. At Resting Springs the thickness of the Cambrian, partly estimated and partly actually measured, is about 1,500 feet, and can not be more than 2,000 feet. About 4 or 5 miles north of Resting Springs the Cambrian is capped by lava.

On the spur of the Kingston Range ending at Resting Springs, at a locality about 2 miles north of the springs, the following section, from the bottom up, was observed:

Section 2 miles north of Resting Springs.

	Feet.
Heavy sandstone, probably all conglomeratic. Observed pebbles were all well-rounded quartzite	2,000
Generally gray shales, with bands of sandstone	1,000
Dark-blue limestone with shales and siliceous limestones, containing trilobites and other Cambrian fossils	100
Quartzitic sandstones and shales	700

About 7 miles east of Resting Springs the rocks in the range, which is part of the Kingston Range, are in part Lower Cambrian, and are a

repetition of those exposed at Resting Springs. There is shown in these mountains about 4,000 feet of Lower Cambrian or earlier rocks. They consist chiefly of reddish and gray sandstone, some calcareous sandstones, and red and blue shales. Fossils were found within about 1,500 feet of the top, and none below that. Although a diligent search was made, they were found only in one ledge, and seemed to be poorly represented even there. About 800 feet below the top of the shale and sandstone formation, fossils are very abundant in some very thin sandstones. They consist mainly of trilobites, *Hyolithes*, and a brachiopod.

In the pass east of Resting Springs, about 800 feet beneath the dark blue limestones, Cambrian fossils were collected. The section consists, from the bottom up, as follows:

Section in pass east of Resting Springs.

	Feet.
1. Reddish sandstones and shales, blue shales, calcareous sandstones, etc. About 2,500 feet from the bottom Cambrian fossils are found, and they are also found 800 feet from the top	4,000
2. Massive dark-blue limestone, apparently containing no fossils	2,000
3. Light-gray limestone in more or less thin layers	300
4. Shaly brown sandstone, with beds of limestone. Contains small trilobites and linguloid shells. Probably Cambrian and possibly Lower Cambrian	20

About 8 miles east of Resting Springs is found No. 5 of the section, consisting of light-gray and dark-blue limestone, more or less massive; thickness, about 2,000 feet. There is an apparent unconformity between this limestone and the underlying formations. Certain parts of the limestone are penetrated by what may be worm borings, now filled with calcite.

About 3½ miles east of Twelvemile Springs is blue and gray limestone. From loose blocks found trilobites were collected, which did not appear to Mr. Rowe to be Lower Cambrian, but to be somewhere between the Trenton and the Lower Cambrian.

On the road from Resting Springs to Tecopa the rocks are largely composed of gneiss containing pegmatite dikes. Upon the gneiss lie shales, sandstones, and limestones of Cambrian or pre-Cambrian age.

On the road from Pahrump ranch to Furnace Creek, along the northern edge of the Kingston Range, Mr. Rowe collected Lower Cambrian fossils from the gray shaly sandstone.

DEVONIAN.

The range was crossed by the writer[a] on the road between Pahrump Valley and Furnace Creek, in the Funeral Range, this road leading past Sulphur Spring and the head of Stuart Valley.

Near Sulphur Spring there outcrops a crystalline, dark-blue, often fine-grained, siliceous, fetid limestone. It is much altered by folding,

[a] J. E. S.

but a small lot of fossils was obtained, which are regarded by Dr. Girty as Devonian. The species are as follows:

Zaphrentis sp.	Spirifer maia.
Orthis sp.	Spirifer maia (small variety)?.
Chonetes deflectus?.	Spirifer argentarius.

About 10 miles northwest of the fossil locality above mentioned occurs a Tertiary conglomerate, containing pebbles of this limestone and quartzite, and from these pebbles another collection of fossils was made, which are determined by Dr. Girty to be Devonian:

Zaphrentis sp.	Spirifer indeterminable.
Crinoid stems.	Athyris? sp.
Bryozoan fragments.	Atrypa missourensis.
Spirifer pinyonensis.	Phæthonides sp.

MESOZOIC.

At the summit of the pass between Manse and Tecopa Mr. Rowe noted that the Paleozoic limestone is overlain by light-gray and chocolate sandstones, reddish and red sandstones, and dark-brown sandstones. Some of these are conglomeratic. Lithologically, this formation is like the Mesozoic of the Spring Mountain Range. These rocks seem to be unconformable with the underlying dark-blue Paleozoic limestone, the dip of the Paleozoic rocks being about 10 or 15 degrees greater. The supposedly Mesozoic rocks are about 1,000 feet thick, and are overlain to the south by a lava bed.

TERTIARY.

On the border of the Amargosa Desert, in the foothills of the north end of the Kingston Range, is found a coarse breccia or conglomerate, containing pebbles of brown or blue fetid limestone and quartzite similar to that found in place in the Devonian series. These pebbles are angular, subangular, or rounded, and are of all sizes up to 2 feet in diameter. They are cemented by a coarse, red matrix, probably chiefly derived from the limestone. The stratification is hardly traceable, yet the deposit is probably water-laid. The general dip seems to be a few degrees northeast. About two miles west of here there occurs a thick deposit of medium coarse granitic arkose, which becomes finer grained and changes to greenish sand. Farther west this sand is seen to overlie a series of soft gray-green shales, sandstones, and granitic arkoses, moderately well hardened. The strike of this series is north and south and the dip 15° E. The finer strata show oscillation ripple marks, such as are formed in standing water, a few inches apart. Somewhat farther west, in the same series, was found a pure white, compact rock, which microscopic investigation shows to be a consolidated volcanic ash. It consists of many fragments of glass in a white opaque dust matrix. The ash underlies greenish, considerably indurated, sandstones, often oxidized to a red color.

This detrital series resembles the series of shales, tuffs, and sandstones exposed near Columbus and Silver Peak, which have been

described by Mr. Turner under the name of the Esmeralda formation, and which carry early Tertiary fossils. The series is also probably the same as that which makes up part of the Funeral Range, and extends over so wide a region south of here. Like all these beds, it is probably early Tertiary.

Mr. R. B. Rowe noted that about Resting Springs there are Tertiary deposits younger than the lavas of the same region.

IGNEOUS ROCKS.

The Tertiary arkoses described above seem to indicate the existence of granite somewhere in the vicinity. As viewed from Pahrump Valley, the southern portion of the Kingston Range in the neighborhood of Kingston Peak has a rugged, massive aspect which may denote the presence of granite. Granite occurs not far southeast of here in the Clarks Peak Mountains, where it cuts the Paleozoic limestones.

At the extreme northern end of those low outlying mountains which lie to the north of the Pahrump Valley there appears to be, as seen from Pahrump Valley, a portion where the topography is low, smooth, and rounded, contrasting with the rugged, banded, stratified rocks farther south. This more monotonous region is probably volcanic.

Mr. Rowe noted the following concerning the igneous rocks subsequent to writing the above:

North of Resting Springs the Cambrian rocks are covered by lavas, which are separated from the underlying rocks by an erosion interval, but are folded to about the same extent. These lavas dip at a high angle and are carved by erosion, like the sedimentary rocks. They do not appear to be as recent lavas as those in the Tertiary deposits. They occupy ancient erosion valleys in the Cambrian.

Between Resting Springs and Tecopa basalt is present in large quantities.

Gneisses in the pass between Sandy and Kingston Peak are cut by many dikes. Kingston Peak itself has a central core of probably pre-Cambrian or basal granite. The overlying quartzite is cut by dark-colored igneous rocks.

STRUCTURE.

According to Mr. R. B. Rowe, the general structure of the Kingston Range seems to be monoclinal, the dip being to the east. At Kingston Peak the Cambrian strata which overlie the central core of granite dip to the north and are folded.

A sketched cross section of the range north of the road between Sandy and Kingston Peak seems to indicate a slight synclinal structure at this point. There is also a great deal of faulting here.

At Kingston Peak there is considerable faulting at right angles to the strike of the rocks, and some parallel to the strike. The pass east of Resting Springs seems to be along a transverse fault.

About 8 miles east of Resting Springs, and about 2 miles northeast of the pass, is a normal fault running 20 degrees west of north. This fault is also shown in the Resting Springs Valley. It brings up the Lower Cambrian shales and sandstones against the overlying limestone. The writer[a] has estimated the throw of the fault, from Mr. Rowe's description, to be about 8,000 feet.

There is an apparent unconformity at this place between the lower Cambrian and the overlying limestone. The limestone strikes N. 28° W., and dips 43° NE.

About 6 miles north of Resting Springs the lavas which lie upon the Cambrian are folded to the same extent as the Cambrian, both dipping northeast 52°. The Cambrian rocks must have been nearly level at the time of the eruption of the lava, although eroded to a considerable extent. The lava flowed over the eroded region, and was deposited in the valleys, against the edges of the strata. Then at a later period both were raised.

A section of a spur of the Kingston Mountains east of Resting Springs shows a monoclinal structure, the dips being uniformly east. The fault above mentioned runs nearly parallel to the range.

OPAL OR CLARKS PEAK MOUNTAINS.

This is a small group of mountains situated on the State line between Nevada and California, just south of the southern end of the Spring Mountain Range. Its chief eminence is Clarks Peak. The mountains are probably to be considered as an extension of the Kingston Range.

Mr. Gilbert[b] notes that in these mountains near Ivanpah the rocks are chiefly limestone, of which the age was not determined. Judging from the fact that the whole southern part of the Spring Mountain Range is Carboniferous and that the Kingston Range is apparently also largely composed of Carboniferous and Devonian, it is likely that the limestone of the Clarks Peak Mountains belongs to much the same period.

Mr. Gilbert further notes that the central portion of these mountains is occupied by a belt of granite, cutting obliquely across the range, with limestone on both sides.

ORE DEPOSITS.

Rich silver ores occur in these mountains, both in the limestone and granite. Farther south large deposits of copper are reported.[c]

PANAMINT RANGE.

The Panamint Range is one of the most important of the ranges auxiliary to the Sierra Nevada, which lie in the belt east of it and run

[a] J. E. S.

[b] U. S. Geog. Surv. W. One Hundredth Mer. Vol. III, p. 32.

[c] Wheeler Surv. Expl. in Nevada and Arizona, War Department, 1871, p. 53

northwest and southeast parallel to its front. The range is about 130 miles in length. At its northern end it merges into lava flows which unite it with the northern end of the Grapevine Range, while at its southern end it passes into low hills of Tertiary strata and associated lavas capped by later basic volcanics. It forms the southwestern barrier of Death Valley, which it fronts with a steep slope.

This range has been very little explored and not much is known concerning its geology. The detail of its mapping, therefore, and especially the differentiation of the Paleozoic which is known to exist in its central portion into the Cambrian and Silurian (as has been done on the accompanying map, Pl. I), is very hypothetical.

SEDIMENTARY ROCKS.

CAMBRIAN.

On the east front of the range, above the road from Furnace Creek in Death Valley to the crossing of the range at Windy Gap or Wingate, a large portion of the range consists of older stratified rocks, which seem, as viewed from a distance, to lie beneath upturned Tertiary sediments and associated volcanics, and are cut through by masses of intrusive granite. No close examination of these older rocks was made, but the drift shows them to be in part finely crystalline blue limestone, and in part quartzite, white, gray, or green, often considerably altered and often coarse grained. The amount of quartzite in the drift implies a considerable thickness of this rock and suggests that the strata are of Cambrian age, as this is the only division of the Paleozoic in this region which contains great amounts of quartzite.

From this neighborhood northward the Panamint Range is composed chiefly of old Paleozoic stratified rocks till near its northern end, as can be plainly seen from Death Valley. On the accompanying map Cambrian rocks are represented as running along the crest of the range, the flanks being occupied by Silurian.

The Panamint Range has been examined by Mr. H. W. Fairbanks[a] for some distance north of the region crossed by the writer. Mr. Fairbanks found on the western side of the range, north of Windy Gap as far as the Pinto Range (which is a spur of the Panamint Range running northwesterly from the Wild Rose mining district), that a large portion of the rocks are mica-schists, quartzites, and marbles, which have been cut by intrusive granite. According to Mr. Fairbanks, the Pinto Range, as viewed from the Argus Range, appears also to be formed of bands of marble of various colors.

In the Grapevine Range at Boundary Canyon Mr. Gilbert[b] found limestones containing imperfect Cambrian fossils. He notes that in that part of the Panamint Range which lies opposite Boundary Canyon the rocks appear from a distant view to be similar.

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[a] Notes on the geology of eastern California: Am. Geol., Vol. XVII, 1896, p. 63.
[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 33, 169, 181.

The strike of the folds is parallel with the trend of the range, so that unless disturbed by cross faulting the same general formations will be found for many miles. Therefore the Cambrian and Silurian have been represented on the map as extending northward until covered by volcanic flows at the northern end of the range.

SILURIAN AND CARBONIFEROUS.

Mr. F. B. Weeks, of the U. S. Geological Survey, visited various parts of the range in 1900. Near Panamint he found quartzite and limestones which he referred on stratigraphic grounds to the Cambrian. South of Shaw Peak (near the northern end of the range) he found a considerable extent of Silurian rocks, with Lower Silurian (Pogonip) fossils, as subsequently determined by Mr. Ulrich. South of here the Silurian Pogonip formation was succeeded by the overlying Eureka quartzite, and still farther south were the Upper Silurian limestones, making the Silurian belt extend to Cottonwood Canyon. At the mouth of Cottonwood Canyon Mr. Weeks found Carboniferous fossils—*Productus*, crinoid stems, and a species of *Seminula* (?).

EARLY TERTIARY.

The eastern flanks of the range fronting Death Valley, as seen on the road between Furnace Creek and Windy Gap, are composed of upturned, yellow-green strata and associated volcanics lying upon the older rocks with no evident unconformity, and partaking of their folds. This belt of interbedded volcanics and sediments grows wider toward the south, and soon completely covers the Paleozoic area, which is wedged out between the younger series and the granite. The same series occurs along a great part of the road which crosses the range to Windy Gap. It consists of layers of calcareous tufa, evidently chemical deposits, with brown conglomerates containing lava bowlders, interstratified with and covered by lava, lava conglomerate, and lava breccia. The lava in these belts proved, in three different samples, to be biotite-hornblende-andesite.

This series of conglomerates, breccias, tuffs, chemical precipitates, and lavas is the same as that exposed on the opposite side of Death Valley, where it forms practically the whole mass of the Funeral Mountains. In the Funeral Mountains these rocks have been provisionally correlated with the Esmeralda formation in the Silver Peak Range, which are chiefly Eocene-Miocene.

LATE TERTIARY.

Mr. H. W. Fairbanks notes[a] that on the northern slopes of the Panamint Range, overlooking Mesquite Valley, there are large areas of gravels, which are unconsolidated and reach an elevation of 6,000 feet, extending nearly to the summit of the range. These may be

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[a] Am. Geol., Vol. XVII, 1896, p. 71.

comparable to the younger semi-indurated conglomerate series in the Funeral Range, which is probably late Tertiary,[a] or may be even Pleistocene.

PLEISTOCENE.

At the foot of the range, above Death Valley, at its southern end, one finds, overlying unconformably the Tertiary deposits just described, bluffs of well-rolled pebbles and small bowlders with perfectly horizontal stratification, the strata making a continual angle with the slight dip of the surface to the east. This horizontality suggests that the deposit is a lake deposit, and connects it with similar conglomerates observed in a similar position in the lower part of Furnace Creek, in the Funeral Mountains. These conglomerates are also intimately connected with the gravels which occupy the bottom of Death Valley and with the salt desert which occurs between the two localities just described.

IGNEOUS ROCKS.

GRANITE.

In the southern portion of the range the core of the mountains for some distance is made up of a body of massive granite, which varies to granite-porphyry. This granite appears to be intrusive into the Paleozoic rocks, but not into the Tertiaries. Along the road which crosses the range east of Windy Gap the granite is hidden beneath these Tertiary rocks, but just south of the road another patch of granite is exposed around Granite Peak. The rock at Granite Peak was shown by microscopic examination to be a biotite-granite, verging toward alaskite, while farther north two samples of granite proved to be biotite-granite-porphyry.

Farther north, according to Mr. Fairbanks,[b] the granite which cuts the ancient limestones and quartzites in the mining regions on the east side of Panamint Valley is a biotite-hornblende-granite with much quartz.

VOLCANIC ROCKS.

As already stated, volcanic rocks make up a considerable portion of the Tertiary formations. Three specimens of these rocks examined all proved to be biotite- or hornblende-andesite, but probably other rocks occur in the series.

Overlying these folded lavas unconformably is a later flow of more basic rock, which covers a considerable area in the neighborhood of Browns Peak, just south of Windy Gap. Two specimens of this rock taken at different places proved to be in one case pyroxene-aleutite, and in the other bronzite-olivine-aleutite.[c] Analysis shows them to be rather siliceous for the species.

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[a] See p. 191.

[b] Am. Geol., Vol. XVII, 1896, p. 72.

[c] See J. E. Spurr, Am. Geol., Vol. XXV, p. 232. Aleutite is transitional between andesite and basalt.

Mr. H. W. Fairbanks states[a] that on the northern slopes of the Panamint Range, overlooking Mesquite Valley, there are scattered sheets of andesite and basalt.

Yet another series of volcanics is exposed in this region. It is that forming the greater part of the Slate Range, which lies immediately west of the southern end of the Panamint Range. The same rocks occur in the region south of Browns Peak, in the Panamint Range, underlying the aleutites. These older volcanics are comparatively light colored and weather reddish; they are, moreover, considerably sheared. Thin sections fail to exactly determine their nature, except that they are really lavas with glassy groundmass, and that they are largely feldspathic. From the shearing it is probable that these lavas are older than those in the folded Tertiary series.

Mr. Fairbanks[b] found forming the highest portion of the Panamint Range for a number of miles east of Panamint a body of ancient rhyolite, which he regards as one of the most ancient lavas observed in the region.

According to Mr. F. B. Weeks, of the United States Geological Survey, who has visited the northern end of the Panamint Range, the Paleozoic rocks are here covered by extensive flows of lava, which appear to be nearly continuous with the lava area at the extreme southwestern end of the Silver Peak Range.

STRUCTURE.

That portion of the Panamint Range between a point opposite Furnace Creek and Windy Gap appeared to the writer, studying it through field glasses, to be, in general, anticlinal. From Cottonwood Canyon northward to Shaw Peak, according to Mr. F. B. Weeks,[c] the Paleozoic strata dip in general north of west.

The Paleozoic and Tertiary strata on the east side of the range, south of Emigrant Canyon, are apparently conformable and have the same folds. There is here a series of alternating anticlines and synclines, having trends due north and south. Each of these folds may be traced continuously for a number of miles. The axes of the folds, as sketched on the map, form a series of straight lines of moderate length, the more southern of which are continually offset to the east from the more northern ones. The explanation of this phenomenon may be a series of east-west faults, which fault the folds systematically to the east on the south side.

Just north of the eastern part of the road which runs from Furnace Creek to Windy Gap, where this road enters the Panamint Range, the strike of the folds changes from north and south to northwest and southeast, and so continues to the extreme termination of the range, in the neighborhood of Owlshead Peak. In all this extreme southern portion there are no Paleozoics, but the Tertiary interbedded sedi-

[a] Letter to the writer. [b] Am. Geol., Vol. XVII, 1896, p. 73. [c] Oral communication.

ments and lavas show the same system of folding as in the Paleozoics, although somewhat less pronounced.

The Pinto Mountains, a spur of the Panamint Range, lying northeast of the Wild Rose mining district, are stated by Mr. Fairbanks[a] to have an apparent monoclinal structure, exposing an enormous thickness of strata whose truncated edges face Panamint Valley.

In the Panamint Range much of the deformation must be of comparatively recent date. We know that much of it occurred since the deposition of the Tertiary beds and associated lavas, since these are involved with the Paleozoics in the upturning.

ORE DEPOSITS.

The following brief note on the ores of the Panamint Range is gleaned from the reports of Mr. H. W. Fairbanks.[b] Near Postoffice Springs gold is found in quartz veins inclosed in limestone, which is folded to a syncline, with slates below and on both sides. The ore is high grade. In the neighborhood of the old town of Panamint are found silver-bearing sulphides of copper, antimony, and arsenic, stromeyerite and tetrahedrite being the most common minerals. The gangue of the veins is quartz, and the veins are found in all the sedimentary formations of the district. North of here, in the Wild Rose district, a similar class of ores is found. Galena is seldom observed.

LEACH POINT AND BURNT ROCK MOUNTAINS.

The roughly defined east-west chain of low, irregular mountains which stretches eastward from the southern end of the Sierra Nevada at El Paso Peak to Pilot Knob is continued farther east in other low, irregular mountains, which just east of Pilot Knob have been called the Burnt Rock Mountains, and still farther, in the same direction, the Leach Point Mountains. On the north of these mountains the narrow Leach Point Valley separates them from the southern end of the Panamint Range. On the south lies the Mojave Desert.

SEDIMENTARY ROCKS.

LIMESTONE.

About 8 miles northeast of Pilot Knob there occurs, along the main traveled road, an outlying spur from the low mountains, which is composed of very sandy blue limestone, amounting almost to a gray quartzite. This is interbedded with shaly and cherty thin-bedded limestones. This rock strikes N. 60° E. and dips E. 65°. It is slightly altered and sheared, and no fossils were found. It forms only a small patch, and is overlain by basalt.

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[a] Am. Geol., Vol. XVII, 1896, p. 66.

[b] Mineral deposits of eastern California: Am. Geol., Vol. XVII, 1896, pp. 144, 151.

EOCENE.

The bulk of the mountains lying east of Pilot Knob are flat topped and slightly pinnacled. They consist of light-colored stratified beds, with intercalated sheets of lava, the whole, in general, capped by black sheets of basalt. Mr. Gilbert[a] has also noted these deposits in this range. They are probably the same as those exposed in the El Paso Mountains, where they contain Eocene fossils, and they are also the same as those which make up the Funeral Range and thus are widely distributed throughout this region.

IGNEOUS ROCKS.

GRANITE.

Along the western edge of these mountains granite is seen to be the basal rock. A specimen collected a few miles north of Pilot Knob appears to be a typical biotite-granite. The relation of this rock to the limestone above described is not known, but it is very likely intrusive in it, if we may judge from the similar occurrences in the Panamint and El Paso ranges and in other neighboring ranges.

VOLCANIC ROCKS.

Some miles north of Pilot Knob typical tordrillite[b] was collected, apparently derived from one of the sheets intercalated in the lake beds. Sheets of black basalt overlie the lake beds and constitute the latest volcanic rock of the region.

STRUCTURE.

The Tertiary beds and intercalated lava sheets seem to be, in general, nearly horizontal, but in one place at least—about 4 miles northeast of Pilot Knob—an anticlinal fold was observed, having a nearly north-south trend, with dips of from 10° to 20° on the limbs.

WHITE MOUNTAIN RANGE.

The important mountain range immediately east of the Sierra has gone by the name of the White Mountains in its northern portion and the Inyo Range in its southern. Inasmuch as the two so-called ranges are not in any way disconnected, but form a complete whole, they will be here, for the sake of convenience, described together under the head of the White Mountain Range, as suggested by Mr. Walcott.[c] The range extends in a northwesterly and southeasterly direction, from the Candelaria Mountains on the north to the neighborhood of Owens Lake on the south, passing at both ends into lower, irregular mountains of lava. No part of the range has been visited by the writer,

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 125.

[b] Differing from rhyolite in the lack of essential ferromagnesian constituents. See J. E. Spurr: Am. Geol., Vol. XXV, 1900, p. 230.

[c] Am. Jour. Sci., 3d series, Vol. XLIX, p. 169.

and the following notes are entirely a compilation of observations, although now for the first time brought together. The observers include Messrs. Gilbert, Walcott, Turner, and Weeks, of the United States Geological Survey, and Goodyear, Gabb, and other geologists of the geological survey of California.

TOPOGRAPHY.

As a rule the topography of the White Mountains is characterized by great relief, with deep canyons and high peaks. On the eastern side of the range there is an abrupt scarp for many miles, while the western slope, although generally steep, is on the average considerably gentler than the eastern. White Mountain Peak, which is at the northern end of the range, is of granite, and is a conspicuous landmark for many miles. It stands exactly on the boundary between Nevada and California.

SEDIMENTARY ROCKS.

CAMBRIAN.

Near the central portion of the range, or at the southern end of the White Mountains proper, Mr. Gilbert[a] early observed a series of quartzites and schists with a little limestone. The age of this series he did not determine. Later Mr. Walcott investigated it and found it to be Lower Cambrian. Mr. Walcott's chief studies were on the western side of the range. In several canyons to the east of Big Pine, namely, Waucobi, Black, and Silver canyons, Mr. Walcott[b] found the following section:

Section east of Big Pine.

	Feet.
4. Upper arenaceous beds	200
3. Alternating limestones and shales	1,000
2. Siliceous slates and quartzites	2,000
1. Siliceous limestones	1,700
Total	4,900

No fossils were found in the lower limestone, but in the lower siliceous series are annelid trails and in places the heads of *Olenellus*, while in the upper limestone are great quantities of Cambrian corals, of the same types as occur in the Silver Peak Range to the east. Mr. Walcott notes that this is the oldest Cambrian fauna known in the western portion of the United States.

Northward from this locality Mr. Walcott found Cambrian rocks along the western face of the range, nearly to its northern end.

On the eastern side of the range he found many of the low mountains lying northeast of Salinas Valley[c] to be Cambrian, and also a

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 169.
[b] Am. Jour. Sci., 3d series, Vol. XLIX, 1895, pp. 141-144.
[c] Personal communication to the writer.

great part of the main White Mountain Range bordering the same valley on the west. At the latter locality Cambrian rocks are cut by great masses of intrusive granite. At the northern end of the range Cambrian rocks occur in considerable quantities on the eastern side, alternating with areas of granite which are intrusive into them.[a]

The rocks have here suffered considerable contact metamorphism by the granite, the limestones being sometimes changed to dolomitic marbles.

SILURIAN.

Mr. Walcott[b] discovered a patch of rocks bearing Silurian (Trenton) fossils on the eastern side of the range, southeast from Big Pine, along the road leading from Waucobi Canyon.

Mr. F. B. Weeks[b] found in 1900, near the head of Mazurka Canyon, rolled remains of crinoids and fragments of bryozoa which indicate that the rocks at this place are not older than Middle Ordovician, and may be somewhat younger.

At the southern end of the range, in the vicinity of Cerro Gordo, Dr. O. Loew[c] reports that the rocks are largely Silurian limestones containing great numbers of fossils, whose genera and species, however, he does not record. These rocks, he notes, are cut into by intrusive masses of granitic rocks.

CARBONIFEROUS.

Mr. Walcott[d] records that Mr. Fairbanks, of the California Mining Bureau, discovered the characteristic Coal Measures fossil, *Fusulina cylindrica*, in the southern end of the range east of Keeler.

Also at the southern end of the range, just below the summit of Cerro Gordo Peak the following Carboniferous fossils were found by Mr. Weeks in 1900, and were determined by Dr. Girty:

Rhipidomella? sp.
Amplexus westi?
Productus fragments.
Marginifera splendens?

TRIASSIC.

Just east of Camp Independence Dr. Horn, of the California geological survey, discovered a fossil in a series of slates with intercalated limestone beds, which was considered by Mr. Gabb[e] to be Triassic.

According to Professor Whitney, these same slates extend northward from Bend City (just east of Camp Independence) for 25 miles. Yet this general region is delineated on the map accompanying this

[a] Personal communication to the writer by Mr. Turner and Mr. Weeks.
[b] Personal communication to the writer.
[c] Ann. Rept. U. S. Geol. Surv. W. One Hundredth Mer., 1876, p. 63.
[d] Am. Jour. Sci., 3d series, Vol. XLIX, 1895, p. 144.
[e] Geol. Survey California, Vol. I, 1865, p. 459.

bulletin as granite, following the preliminary geological maps of the State of California, published in 1891 by the State Mining Bureau.

South of the locality above mentioned, near the crest of the range, halfway between Independence and Owens Lake, Mr. Walcott[a] found a single block containing Triassic fossils.

Mr. Turner[a] traced the Triassic rocks as a continuous belt between the two localities above mentioned and also some distance farther south along the western flanks of the range. Mr. Turner states that the rocks consist essentially of Triassic lavas with interbedded tuffs. The same rocks occur on the western side of Owens Valley, northwest of Owens Lake, on the flanks of the Sierras, and here also are of the same character.

From the lithology of the Triassic rocks above mentioned a probable correlation is established with the Koipato group of the fortieth parallel Triassic, as defined by King.

PLIOCENE.

Just east of Big Pine Mr. Walcott[b] has described a considerable area covered by consolidated stratified deposits, which he regards as lake beds. The strata consist of fine calcareous, arenaceous, and argillaceous sands with layers of fine conglomerate, the whole being covered by angular débris washed down from the mountain since the deposition of the stratified material. The deposits are coarser near the mountains and finer as the distance increases. Some of the white beds are made up almost entirely of fresh-water shells, concerning which Dr. Dall says: "Any of them may be recent or Pliocene. My impression from the mass is that they are Pleistocene." Mr. Walcott[c] found these beds reaching from the bottom of the valley up to a height of 3,000 feet above the valley, or to an actual height above sea level of about 7,000 feet. As an explanation for the great height at which these deposits are found, Mr. Walcott mentions two main hypotheses—first, that a lake 3,000 feet deep existed over the site of the present Owens Lake, and, second, that the Inyo or White Mountain Range has been elevated since the deposition of the lake beds, carrying up these beds with it. He inclines to the view that the latter is the correct hypothesis, on account of the steep easterly scarp of the range, which might be taken as a fault scarp, and from other considerations.

The character of these beds, as described by Mr. Walcott, and their nearly horizontal attitude are identical with those of deposits of the late Pliocene lake which has already been described by the writer as observed by him in numerous localities in Nevada, but chiefly in the region between Lake Mono and Carson. All these beds he has considered as the deposits of a late Pliocene lake—the Lake Shoshone of

[a] Personal communication to the writer. [b] Jour. Geol., Vol. V, p. 340. [c] Ibid., p. 345.

King.[a] In the region just north of Lake Mono he found the highest deposits of this lake at an altitude of 7,100 feet, and came to the conclusion that the uppermost deposits of the ancient Lake Mono formed part of the deposits of the same great water body. When the great lake stood at this altitude it must have been connected by numerous straits with the valley of the present Owens River, which formed an arm of the same lake. The uppermost limit of the lake beds noted by Mr. Walcott coincides almost exactly with the uppermost limit in the vicinity of Lake Mono and to the north of it. It is therefore likely that the deposits on the slopes of the White Mountain Range are to be correlated with these other deposits. The age indicated by the fossils found by Mr. Walcott also coincides with the other determinations made in other localities, all combining to indicate a period between late Pliocene and early Pleistocene.

If this is the case, no local elevation of the White Mountains can be inferred from the position of the lake beds at the comparatively great altitude where they are found, since the altitude is similar over the whole region. As was inferred by the writer with reference to the region around Lake Mono, there appears to have been a general uplift of mountain and valley throughout this whole region, lifting the deposits of the Pliocene lake about 1,000 feet higher than farther north.

South of Owens Lake Mr. Turner found[b] well-stratified sands, gravels, and tuffs, occupying a large portion of the valley beneath the overlying Pleistocene accumulations, and having a slight dip westward. These may belong to the same series as above described. The same beds are mentioned by Mr. Fairbanks,[c] who notes that at Owens Lake they reach an elevation of at least 1,500 feet above the lake surface. Mr. Fairbanks regards these beds as formed under water.[d]

IGNEOUS ROCKS.

GRANITIC ROCKS.

Mr. Gilbert[e] noted that the eastern ridge of the White Mountains, east of Deep Springs Valley, is composed of granite. The map of the California State Mining Bureau[f] shows a number of other granite areas. On this map the whole northern end of the range in the vicinity of White Mountain Peak is shown to be of granite, and also most of the range from Loehr Peak southward to Deep Springs Valley. Farther south, a considerable area of granitic rocks is shown south of

[a] See pp. 117, 119, 123.
[b] Personal communication.
[c] Am. Geol., Vol. XVII, p. 69.
[d] Mr. M. R. Campbell's later notes on these gravels (Bull. U. S. Geol. Survey No. 200, p. 20) show that they are gently folded lake sediments containing much volcanic tuff. They are very likely pre-Pliocene (Eocene or Miocene), like the lake beds in Funeral Range.
[e] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 315.
[f] Preliminary mineralogical and geological map of the State of California, 1891.

Waucobi Peak,[a] while a small area is shown southwest of Salinas Valley, also in the center of the range. In the low mountains lying northeast of Salinas Valley two considerable areas are shown.

From personal communications of Messrs. Walcott, Turner, and Weeks, further information on the extent of the granite has been obtained. The two northern granite areas represented as separate on the above-cited map appear to be continuous between Loehr Peak and White Mountain Peak. On the eastern side of the northern end of the range a great deal of granitic rock is found, cutting the Cambrian sediments. Farther south, the granite area south of Waucobi Peak extends southeastward in a continuous belt to the area southwest of Salinas Valley, and the Cambrian beds west of Salinas Valley are cut through by masses of the same rock.

VOLCANIC ROCKS.

As noted above, many of the Triassic rocks are lavas. There are, moreover, some areas of Tertiary and Pleistocene lavas, as represented on the map. Mr. Gilbert[b] noted some basalt just east of Big Pine. The map of the California Mining Bureau, above mentioned, shows an area of volcanic rocks lying on the west flanks of the range in the neighborhood of Waucobi Peak, and connecting westward across Owens Valley with a larger area of lava on the eastern slopes of the Sierra. The same map also shows volcanic rocks lying on the northern slopes of the granite of White Mountain Peak, at the northern end of the range, and shows a great area of lava lying southeast of Owens Lake, and forming the southern end of the range. Mr. Turner found that the mountains east of Sandy Springs, which form a kind of connection between the northern end of the White Mountain Range and the Silver Peak Range, are mostly volcanic.

ORE DEPOSITS.

The following notes are taken from Mr. H. W. Fairbanks's writings.[c] Silver-lead ores, chiefly in limestone, are found about Cerro Gordo and southeast of Independence.

Auriferous quartz veins are abundant. They are found north of Cerro Gordo, in the Beveridge district, in the Alhambra Hills, 5 miles north of Lone Pine, between Independence and Big Pine, and east and northeast of Bishop Creek. The veins are chiefly in or near granite, often at or near the contact of it with slates or limestones. They probably have a genetic connection with the granitic intrusion.

[a] According to Professor Whitney, however (Geological Survey of California, Geology, Vol. I, p. 459), the western face of the range, south of Waucobi Peak to Bend City (just east of Camp Independence), is composed of tilted slates and other stratified rocks. If this is the case, these stratified rocks are undoubtedly continuous with the Triassic rocks south of Camp Independence.

[b] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 124.

[c] Report California Min. Bureau, 1894, p. 475; Am. Geol., Vol. XVII, No. 3, pp. 145, 146, 149, 150.

STRUCTURE.

Mr. Gilbert[a] gives a cross section of the range east of Big Pine, which exhibits several adjacent folds of moderate dip, broken by a number of faults. According to Mr. Gilbert's section the faults are not directly expressed in the topography.

Later Mr. Walcott[b] described several sections of the White Mountain Range, in the same general region as that in which Mr. Gilbert's section was made. Mr. Walcott also finds the range made up of a number of adjacent folds broken by faults, and finds the chief fold to be a closely compressed syncline overthrown to the east, thus presenting a type of structure common in the Appalachians.

DARWIN OR ARGUS RANGE.

This range is low and of no great importance. It lies between the Panamint Range and the Coso Mountains and is south-southeast of the White Mountain Range. The range is about 70 miles in length and very narrow. Through its northern portion Darwin Canyon runs.

SEDIMENTARY ROCKS.

Mr. H. W. Fairbanks[c] notes that the eastern face of the Argus Range, from Darwin to Modoc, is made up largely of limestone, which sometimes forms the crest of the range and is present in great thickness. Besides the limestone there is also calciferous quartzite.

The age of this Paleozoic series is not known, but it is provisionally mapped as Cambrian, in view of the probable age of the rocks of the Panamint Range to the east.[d]

IGNEOUS ROCKS.

GRANITE.

According to Mr. Fairbanks,[e] granite occupies a considerable portion of the Argus Range, forming part of a continuous body which stretches from the Mojave Desert to the Sierra Nevada. In general, it is a granular, light-colored, biotite-hornblende rock.

VOLCANIC ROCKS.

From Darwin Canyon north to the 36° 30′ parallel the mountains are described as black lava hills on the topographic map of the Wheeler Survey (65-D). This same portion of the range is also represented as volcanic on the preliminary geologic map of California,

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 34.

[b] Am. Jour. Sci., 3d series, Vol. XLIX, 1895, p. 169.

[c] Am. Geol., Vol. XVII, 1896, pp. 65, 149.

[d] Since writing the above Mr. F. B. Weeks has informed the writer that in 1900 he found in Shepherd Canyon heavy exposures of quartzite overlain by limestone, which he had no hesitation in referring on stratigraphic grounds to the Cambrian.

[e] Op. cit., p. 72.

issued by the California mining bureau in 1891. On this map the lava is represented as extending southward along the range to a point beyond Malurango Peak.

Mr. H. W. Fairbanks[a] reports numerous flows of andesite and basalt through the Argus Range, forming inclined plateaus on the mountain slopes. One of these basalt flows is exposed in Argus Gulch, and beneath it is an ancient river channel filled with clay and gravel.

The southern portion of the range has a volcanic appearance, as seen by the writer from a point farther south.

ORE DEPOSITS.

Mr. Fairbanks[b] states that a large number of gold-bearing quartz veins are scattered through the southern portion of the Argus Range. There is also, in the neighborhood of Darwin and Modoc, considerable galena, rich in silver, in chambers in the limestone.

SLATE RANGE.

The Slate Range lies in Panamint Valley, between the southern end of the Panamint and that of the Darwin or Argus ranges. It has an extent of only about 12 miles, and is comparatively low and narrow. The range derives its name from the fact that its rocks have been sheared so as to assume a slaty structure.

SEDIMENTARY ROCKS.

PALEOZOIC.

Mr. H. W. Fairbanks states that metamorphic strata appear prominently in the Slate Range.

TERTIARY.

At the extreme southern end of the range schistose volcanics are overlain by cream-colored Tertiary sediments, capped by later basaltic lava. These Tertiary sediments are probably the same as those exposed in the Panamint Range just east of here, and also in the Funeral Mountains.

IGNEOUS ROCKS.

VOLCANIC ROCKS.

So far as could be observed, the range near Windy Gap and from here southward to the extreme end consists of uniform rocks. As examined under the microscope, these rocks seem to be sheared feldspathic lava, much altered. The exact nature of the lava could not be determined, but it consists chiefly of a glassy groundmass, with phenocrysts of feldspar. One specimen studied was so sheared as to be comminuted into bits.

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[a] Am. Geol., Vol. XVII, 1896, p. 73.   [b] Ibid., pp. 145, 149.

The age of the schistose volcanics is not known, except that they are older than the basalt and probably older also than the Tertiary sediments. Their shearing suggests a considerable age and also suggests that they may be connected with the granites of the Panamint Range, or with the ancient rhyolite of that range east of Panamint,[a] which rhyolite has a probable connection with that in the vicinity of Johannesburg.

At the northern end of the range the slaty rocks appear to be in part overlain by later volcanic flows, as seen from the south end. There are probably basalts similar to those at the south end of the range.

COSO RANGE.

IGNEOUS ROCKS.

GRANITE.

The central portion of the Coso Mountains is made up of granite and gneissoidal rocks.[b] The rock in this range is reported by Mr. H. W. Fairbanks[c] to be a coarse, easily decomposed granite, and the same writer states that granite makes up most of the rest of the range.[d] This granite is continuous with the granite of the Sierra Nevada.

VOLCANIC ROCKS.

Mr. Gilbert[e] notes that the western base of Coso Range, south of Owens Lake, appears to be entirely eruptive. Mr. Fairbanks[f] has noted volcanic rocks belonging to two distinct periods of eruption in the western part of the range. To the older rocks belong rhyolites and andesites, while the younger consist of extensive flows of basalt (so recent in origin that their surfaces have been but slightly modified by erosion), reaching southward in long arms into Salt Wells Valley.

EL PASO RANGE.

The El Paso Range is a rugged, irregular bunch of mountains constituting an outlier of the southern Sierra Nevada, south of the Coso Range. The general trend of its ridges is east and west. It is bounded on the north by Salt Wells Valley and on the south by the Mohave Desert.

SEDIMENTARY ROCKS.

According to Mr. H. W. Fairbanks,[g] the stratified rocks of a metamorphic series (probably Paleozoic) form a part of the El Paso Range and are cut by the granite.

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[a] See p. 204.
[b] Geol. Surv. California, Vol. I, p. 474.
[c] Report California Min. Bureau, 1894, p 474.
[d] Am. Geol., Vol. XVII, 1896, p 145.
[e] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 124.
[f] Am. Geol., Vol. XVII, 1896, p. 73.
[g] Ibid., p. 65.

EARLY TERTIARIES.

Mr. Gilbert[a] has described a series of semiconsolidated beds in Redrock Canyon, in the southern part of the El Paso Mountains. These beds dip westward at angles ranging from 15° to 30° and consist of semiconsolidated sand, gravel, and volcanic tuffs interbedded with basalts and rhyolites. The gravels contain pebbles of quartz and various volcanic rocks.

Mr. H. W. Fairbanks[b] describes the same series on the northern slope of the El Paso Range, where it also consists of clays, sandstone, volcanic tuffs, and interbedded lava sheets. The whole thickness is estimated to be 1,000 feet or more, and the series extends over a considerable area between the El Paso Range and the Sierra Nevada. Between clay strata, apparently below the tuffs, southeast of Black Mountain, a seam of coal 14 inches thick occurs in this series. In the clay above the coal leaf impressions were found, which Dr. F. H. Knowlton considered as probably belonging to the Eocene. Mr. Fairbanks notes that andesite appears as flows between the beds as well as in dikes cutting them and as sheets capping them.

The series of semiconsolidated, tilted tuffs, sands, gravels, and volcanic sheets is evidently identical with that which constitutes the Funeral Range and the southern end of the Panamint Range, as described. As has already been stated, these latter beds are believed to be the same as those still farther north, in the neighborhood of Silver Peak.

IGNEOUS ROCKS.

GRANITE.

Mr. Gilbert[c] notes that the El Paso Mountains have a core of granite. The same is noted by Mr. Fairbanks.[d]

VOLCANIC ROCKS.

Mr. Fairbanks[e] notes that quartz-porphyries appear for several miles along the El Paso Range. The writer found that near Johannesburg and Randsburg, which lie among low hills just east of El Paso Range, the principal rock is an ancient sheared rhyolite. To one looking from this point westward this same rhyolite appears to form a considerable portion of the eastern end of this range also. It is possible that this is the same rock that Mr. Fairbanks describes as quartz-porphyry. It is the most ancient volcanic rock found in the region, and is probably nearly contemporaneous with the schistose volcanics described at the southern end of the Slate Range. It

[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 142.
[b] Notes on the Geology of Eastern California: Am. Geol., Vol. XVII, 1896, p. 67.
[c] Op. cit., p. 124.
[d] Am. Geol., Vol. XVII, 1896, pp. 65, 152.
[e] Ibid., p. 152.

underlies the early Tertiary sediments. Mr. Gilbert[a] notes that at the eastern end of the El Paso Mountains there is a large mountain of acidic lavas, inclosing and nearly concealing a core of granite.

Mr. Gilbert also notes that the El Paso Mountains are flanked to the south by basaltic and trachytic rocks. Mr. Fairbanks[b] describes andesites as occurring freely in this range. The trachytes described by Mr. Gilbert are probably the andesites of Mr. Fairbanks, since trachytes, as now understood, are very rare in this region.

STRUCTURE.

Reasoning from the tilting of the early Tertiary sediments, Mr. Fairbanks has inferred three distinct movements of Black Mountain in the El Paso Range. As the result of these movements, the Tertiary beds have been elevated, tilted, and extensively eroded.

ORE DEPOSITS.

According to Mr. Fairbanks,[c] the granite of the El Paso Range has been in different places mineralized, and contains a small amount of gold.

THE HILLS FROM RANDSBURG EAST TO PILOT KNOB.

Forming a sort of continuation of the El Paso Range to the east is a series of low, detached, rounded, or level-topped buttes, connected by low ridges or Pleistocene detrital slopes, or entirely separated by an undulating detritus-covered desert. These hills have a general east-west trend.

SEDIMENTARY ROCKS.

ARKOSES.

On the north slopes of Malapai Mountain, about 4 or 5 miles northeast of Johannesburg, the hornblende-pyroxene-aleutite, which makes up the higher portion of the mountain, is underlain by banded or bedded rocks, which at first have the aspect of altered volcanics, but which, when examined microscopically, turn out to be arkoses of different degrees of coarseness. Most of them are granitic, while some appear to be in part derived from rhyolite. These arkoses probably overlie the ancient rhyolites. They are firmly consolidated, and they may belong to the series of Eocene sediments found near here, especially in the El Paso Range to the west, and on the east in the Leach Point Mountains.

On Pilot Knob, according to Mr. Gilbert,[d] are exposed about 2,000 feet of volcanic products, probably tuffs, overlain by basaltic lava. These lie upon the granite, which is the base of the knob.

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[a] U. S. Geog. Surv. W. One Hundredth Mer., Vol. III, p. 124.
[b] Am. Geol., Vol. XVII, 1896, p. 69.
[c] Ibid., p. 152.
[d] Op. cit., p. 124.

IGNEOUS ROCKS.

The lower portion of Pilot Knob is of siliceous biotite-granite. To the south, southeast, and west this same body of granite extends for miles. Many of the numerous small hills, which emerge from the general plateau level of the desert area of granite, are often capped by patches of basic lava or stratified Tertiary sediments.

All the hills in the vicinity of Randsburg and Johannesburg consist of ancient sheared rhyolites, often considerably decomposed. When fresh, the rock appears to be a biotite-rhyolite, but as often as not the biotite has completely disappeared on account of decomposition, and the other minerals, notably orthoclase, have also become considerably altered. It is in this rock that the gold-bearing veins of the district occur, and the rhyolite has been locally altered at the time of the introduction of the ores so as to become a semijasperoid, and sometimes even passes into vein quartz by a process which appears to be chiefly replacement.

This ancient sheared rhyolite resembles the sheared volcanics of the southern end of the Slate Range.

The greater portion of Malapai Mountain is made up of a considerable thickness of lava, which overlies the rhyolite and underlies basalt. Its intermediate age is also at once evident from its appearance. A number of specimens of this rock have been studied and show it to be probably a hornblende-pyroxene-biotite-aleutite. This rock has no apparent banding, and has a great variety of texture exposed by the erosion which it has undergone.

The basaltic rock which caps Pilot Knob was also encountered just west of this mountain. The specimen taken here proves to be a pyroxene-basalt, evidently belonging to the same general series as the olivine-basalt of the region. In the Browns Peak region, in the southern end of the Panamint Range, the same basalt occurs in a number of buttes, capping other rocks.

At Johannesburg a dike of pyroxene-olivine-diabase-porphyry was found, cutting the ancient rhyolites. This dike is probably to be correlated with the basaltic flows.

The succession of igneous rocks in this district, therefore, is, so far as made out, biotite-granite, biotite-rhyolite, hornblende-pyroxene-biotite-aleutite, pyroxene-basalt, and pyroxene-olivine-diabase-porphyry.

ORE DEPOSITS.

Gold-bearing veins are very numerous in the ancient rhyolite in the vicinity of Johannesburg and Randsburg. The veins generally consist of a central thin seam of quartz, flanked above and below by sheared, silicified, and discolored country rock, which also may carry quartz nodules or segregations. There are also larger veins of clearer bluish quartz. Certain portions of these quartz veins and altered

sheared zones carry free gold in such quantities as to make them high-grade ores. The schistosity of the rocks has a general northeast dip of 15° and 20°, and the veins are usually conformable to this.

SIERRA NEVADA.

Properly speaking, the Sierra Nevada does not constitute part of the present study. It was thought best, however, to include the eastern edge of this important mountain chain so as to show its relations to the region lying east of it. For the sake of uniformity a few brief descriptive notes will be given. The region is, geologically, a complicated one, but has been the subject of a great amount of careful study by many geologists, while the Basin region has been left almost untouched.

As a topographic feature the Sierra Nevada is a broad range, attaining considerable elevation and having many well-defined peaks. Its eastern face constitutes a sharp western limit to the interior Basin region, which is characterized by narrow ridges of generally less height, with flat desert valleys between. Unlike the Basin ranges, the Sierra Nevada is well watered and wooded, and from this circumstance has derived a different minor topography from that of the Basin ranges.

SEDIMENTARY ROCKS.

Mr. Turner[a] states that it is probable that there are in the Sierra Nevada formations ranging in age from Archean or Algonkian to Recent. The rocks have been strongly affected by compression of the crust, which has produced close folding and schistosity, and has frequently obliterated the original nature and age of the sediments. In different parts of the range,[b] however, the great series of auriferous slates has been found to contain Silurian, Carboniferous, Triassic, and Jurassic fossils. The superjacent series of less altered rocks consists of strata ranging from the Upper Cretaceous through the Tertiary. Large portions of the range are covered with auriferous river gravels of Neocene age.

Within the area represented by the map accompanying this bulletin the stratified rocks occupy only restricted areas, surrounded by great masses of granite.

CAMBRIAN.

Just west of Mono Lake there is a considerable patch of quartzites and schists, mapped by Mr. Turner[c] as Paleozoic. Mr. Walcott[d] subsequently visited these rocks, and considers them identical with the Cambrian series of the White Mountains. Southward from here a

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[a] Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 531.
[b] H. W. Turner: Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 445.
[c] Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, Pl. XVIII.
[d] Personal communication to the writer.

short distance, on the North Fork of San Joaquin River, is an area of similar rocks, according to Mr. Turner. Still farther southeast, not far from Big Pine, in Owens Valley, Mr. Walcott found small patches of Cambrian, and considers that these separate occurrences may belong to a single belt.

CARBONIFEROUS.

On the extreme western edge of the map, northeast from Mariposa, is an area of Carboniferous rocks which has been studied by Mr. Turner.

TRIASSIC.

Northwest of Owens Lake, on the eastern flanks of the Sierra Nevada, is an area of Triassic beds, consisting mainly of ancient lavas and tuffs, similar to the Triassic rocks of the White Mountains on the other side of the valley.

Some distance south of here the region around Owens Peak consists of rocks similar to the Triassic formations just described. No fossils were found in this region.

Just east of Silver City, which is southeast of Lake Tahoe, Mr. Turner has mapped several small exposures of sedimentary rock. In his reconnaissance map[a] these areas are mapped as doubtful Juratrias.

JURASSIC.

A long tongue of the Jurassic rocks which occur at Mariposa comes into the map at its extreme western end.

IGNEOUS ROCKS.

The Sierra Nevada contains enormous quantities of igneous rocks, both coarse and fine grained, and both surface flows and plutonic and dike masses. According to Mr. Turner,[b] the coarse-grained rocks consist mostly of granite and granodiorite, with diorite, gabbro, etc., while the abundant Tertiary lavas consist of andesite, rhyolite, and basalt.

In the area covered by the map accompanying this bulletin (Pl. I) the greater part of the Sierras consist of coarse, granular, igneous rocks, among which granite and granitic rocks occupy the chief place.

Overlying the ancient granites, within the limit of this map, come occasional areas of Tertiary lavas. Mr. Turner has kindly supplied the writer with notes concerning two of these regions, one of which is in the neighborhood of Silver City and the other at the extreme southern end of the range, just north of the cut of the Southern Pacific Railway, between Tehachapi and Mojave. At the first-named locality Mr. Turner observed at one point a thickness of half a mile of

[a] Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, Pl. XVIII.
[b] Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 470.

volcanic lavas and tuffs. The lavas occupy several separated areas, and in them occur the ore deposits of the region. In the second locality Tertiary lavas with Tertiary sediments make up the southern flanks of the range.

On the flanks of the range, about Fish Springs, are flows of basalt, described by Mr. W. A. Goodyear.[a] Mr. H. W. Fairbanks[b] suggests that these may be of the same age as the basalts of the Coso Range. According to Mr. Fairbanks, also, "andesite covers a great stretch of country about the head of Owens River, forming the crest of the Sierra Nevada between it and the head of the North Fork of the San Joaquin River."

STRUCTURE.

It has been recognized, from the evidence which the Mesozoic strata of the Sierra Nevada offer, that the folding of the range was initiated at the close of Jurassic time, after the Mariposa beds were deposited.[c] During the period which succeeded this Jurassic movement erosion produced great changes, and gradually brought about the formation of a topography of little relief, the mountains being low, the valleys broad, and the streams sluggish. This period appears to have reached its maximum during the Miocene.[d] Subsequent to the development of this style of topography there was a general disturbance which brought about the acceleration of the streams and the cutting of deep valleys, leaving high ridges between. This disturbance apparently consisted in part of differential movement, but there are evidences that the whole mass of the Sierra was uplifted at least 4,000 feet, and possibly as much as 7,000 feet.[e] Mr. Turner[f] concludes, from the fact that the Neocene Gulf deposits, at the very west edge of the range, have been elevated at least 1,000 feet above their original position, that the mountains were uplifted as a whole, and not by a tilt to the westward, for in the latter case the west edge of the block so tilted would remain approximately at its original elevation.

During the latter part of the time that the Sierra Nevada region was being worn down, a great series of auriferous gravels was deposited by the sluggish streams. These gravels, after the uplift and the acceleration of the drainage, remained often in the highest parts of the range and in the regions between the present river valleys, especially where protected by later cappings of lava.

The eastern face of the Sierra, for a distance of several hundred miles, is very steep, contrasting strongly with the comparatively uniform and gentle slope on the west. The earliest observers saw in this a probable fault scarp. Mr. Clarence King[g] was one of the first

[a] Rept. of Cal. State Mining Bureau, Vol. VIII, pp. 271-272.
[b] Am. Geol., Vol. XVII, p. 73.
[c] H. W. Turner, Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 532.
[d] J. S. Diller, Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 421.
[e] Ibid., p. 433.
[f] Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 443.
[g] U. S. Geol. Expl. Fortieth Par., Vol. I, p. 744.

of these, and the hypothesis has been accepted by nearly all succeeding geologists.

The observations most in favor of the existence of a fault are those of high gravels on the very summits of the mountains above the steep eastern scarp. Mr. Diller[a] has noted, at the northern end of the range, that these gravels are displaced by a fault having about 3,000 feet vertical displacement, which extends along the eastern face of the range. Mr. Russell[b] also found water-worn gravels on the top of the range to the west of Mono Lake, at an altitude of about 11,500 feet. Mr. Turner[c] found well-rounded pebbles on the main summit of the range a few miles northwest of Tower Peak, at an elevation of over 9,000 feet. Mr. Turner observes that these gravel patches along the crest of the range undoubtedly represent remnants of Neocene river beds, now almost entirely eroded.

The writer does not know of any case where actual faulting has been proved by displacement of rocks, unless it is the case of the displacement of recent lavas along the crest north of Honey Lake, described by Mr. Diller.[d] Even in many of the instances where river gravels have been found at the summit of the range, it is possible that some other hypothesis may be found to explain their presence, as well as that of faulting. Along most of the range the rocks of the Sierra Nevada scarp do not stop abruptly, but are found in the ranges lying next east. The eastern face of the range is not the boundary between the granites on the west and the volcanics on the east, as supposed by Russell.[e] In the White Mountain, Pine Nut, and other ranges lying next east of the Sierra, granitic rocks are found forming the core, and also in some of the ranges farther east, growing, however, continually lower until no longer exposed by erosion.

Mr. King[f] considered that the fault along the eastern scarp was formed either within the Eocene or at the close of Eocene time, since it evidently existed before the formation of the Miocene Piute Lake, which was an inclosed inland body of water and was shut off from the sea by the barrier of the Sierra. On the other hand, Mr. Diller[g] considered that the fault along the eastern scarp must have been formed very recently, in post-Tertiary time, since the Tertiary river gravels and most of the volcanics are displaced. South from the area observed by Mr. Diller, however, Mr. Lindgren[h] found that the eastern slope of the range was formed before the eruption of the andesitic lavas.

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[a] Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p 432.
[b] Eighth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 322.
[c] Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 442.
[d] Eighth Ann. Rept. U. S. Geol. Survey, Pt. I, p. 429.
[e] Eighth Ann. Rept. U. S. Geol. Survey, Pt I. p. 371.
[f] U. S. Geol. Expl. Fortieth Par., Vol I, p. 744.
[g] Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, p. 432.
[h] Bull. Geol. Soc. Am., Vol. IV, pp. 257-298.

Since writing the above the writer has obtained the following additional information:

On the east front of the Sierra, between Carson and Markleeville, Mr. Lindgren has found evidence of recent faulting along the base of the mountains. Near Genoa, Pleistocene alluvial deposits are displaced some 40 feet by this fault. Another point is the behavior of the Carson River, which, on emerging from the mountains, increases its grade abruptly, suggesting comparatively recent dislocation of its valley. Mr. Lindgren believes that the first dislocation along the eastern face of the Sierra Nevada took place at the close of the Cretaceous and that movement has continued at intervals down to the present day. The faulting was not simple, but complex. A number of more or less parallel faults may be distinguished within a belt 25 miles wide.[a]

[a] Auriferous gravels of the Sierra Nevada: Jour. Geol., Vol. IV, No. 8, and oral communication to the writer.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 208.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, Director

THE

GEOLOGY OF ASCUTNEY MOUNTAIN, VERMONT

BY

REGINALD ALDWORTH DALY

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ILLUSTRATIONS.

A. GENERAL VIEW OF ASCUTNEY MOUNTAIN, PIERSON PEAK, AND LITTLE ASCUTNEY MOUNTAIN.

From a point on the New Hampshire side of the Connecticut River [illegible]

B. ASCUTNEY MOUNTAIN AND THE TERRACES OF THE [illegible]

Ascutney [illegible]

THE GEOLOGY OF ASCUTNEY MOUNTAIN, VERMONT.

By R. A. DALY.

INTRODUCTION.

Nature of the investigation.—The following pages embody the results of an investigation of the lithology and geölogy of a plexus of eruptive rocks and of the metamorphic aureole in schistose rocks surrounding the igneous bodies. The field work was begun in 1893, but numerous interruptions prevented the completion of the study until the present year. In the meantime an elaborate series of chemical analyses was made by Dr. Hillebrand (in 1896) and the results were published on pages 68–70 of Bulletin 148 of the United States Geological Survey. These analyses are here republished, with the oxides arranged in the order recommended by Dr. H. S. Washington.[a]

Acknowledgments.—The writer's best thanks are due to Dr. Hillebrand, for the completeness and accuracy of his analyses; to Prof. J. E. Wolff, of Harvard University, who not only suggested this piece of research, but also greatly assisted in the petrographical determinations; to Professor Rosenbusch, of Heidelberg, who likewise aided in the laboratory study of the collected material; to Dr. F. P. Gulliver, for the care he bestowed on the preparation of the topographical map; and especially to Dr. T. A. Jaggar, of Harvard University, who, after carrying on several weeks' field work in the area in collaboration, placed his notes and rock collection at the disposal of the writer. In addition, Dr. Jaggar has done much in the microscopic investigation of the specimens and in preparing the photographic illustrations for this report. He has also read the manuscript, which has been improved both in form and contents by his valuable suggestions.

[a] Am. Jour. Sci., 4th series, Vol. X, 1900, p. 59.

CHAPTER I.

PHYSICAL GEOGRAPHY.

GENERAL TOPOGRAPHY OF THE AREA.

Mount Ascutney is the most conspicuous elevation seen by the traveler in ascending the Connecticut River (see Pl. I, *A*). The mountain, as well as the rest of the area considered in this paper, is situated on the right bank of the river and near the town of Windsor, in southeastern Vermont. Though having an elevation of little more than 3,000 feet (915 meters) above sea level, Ascutney is very prominent as it rises from the floor of the deeply trenched master valley of New England. The railway bridge over the Connecticut at Windsor is but 301 feet (92 meters) above sea level; the summit of the mountain is, according to Dr. Gulliver's determination, 3,114 feet (950 meters) above the same datum[a] and lies only 3 miles from the river (see Pl. I, *B*). Thus the mountain is considerably more imposing than many other peaks in New England, which, although of the same or even greater height, yet rise from a more elevated base. Additional scenic importance attaches to Ascutney on account of its isolated position. Among the nearer noteworthy elevations are Ludlow and Shrewsbury mountains and Killington Peaks of the Green Mountain Range; accordingly, for a distance of 20 miles in every direction, the beautifully compact, broadly conical outline of Ascutney forms a principal feature of the landscape. Largely for this reason the mountain enjoys a special reputation for beauty among the inhabitants and tourists of New England.

The conditions for field work are good except in some parts of the main mountain, where thick second-growth timber effectually conceals the eruptive rocks. Two good paths to the summit, one from Brownsville, the other from the Windsor side, were open in 1898. The mountain can, however, be easily climbed from any direction.

The softened profiles of the mountain suggest, and a study of the geological structure of the region proves, that Ascutney is a residual of erosion (see Pl. VII). It has been carved out of this part of the once lofty Appalachian mountain system where the sedimentary rocks of the range have been intruded by several stocks and thick dikes of igneous rock. The relief features of the area discussed thus belong to the same category as the very common sugarloaf peaks of Vermont,

[a] C. H. Hitchcock estimated the height to be "about 3,168 feet:" Geology of New Hampshire, Vol. I, 1877, p. 180.

located on intrusive granites and syenites. The geological map (Pl. VII) indicates in an almost diagrammatic fashion the sympathy between relief and rock composition. Ascutney itself owes its existence primarily to a great stock of quartz-syenite. The picturesque ridge of Little Ascutney is held up by a strong rib of intrusive syenite-porphyry associated with other eruptives more resistant to the weather than either the gabbro-diorite stock on the north or the gneisses on the south. The shapely cone north of Little Ascutney, which, for purposes of convenience in this report, has been named "Pierson Peak" (after the hospitable owner of the farm at the base of the hill), is strictly controlled in form by a small elliptical stock of alkaline syenite cutting the softer diorites.

Apart from other more general considerations, the fact that these eruptive rocks are more resistant to weather than the surrounding schists is clear from the nature of the slopes and profiles at the contacts. As a rule there is an abrupt steepening of the ascent along the radiating spurs of the main mountain just above the contact between the sedimentary and eruptive rocks. At the same line of contact there is likewise a sudden change of gradient in the streams draining the mountain, as if corrasion were considerably easier on the schists than on the eruptive rocks. An example is seen at the beautiful "Crystal Cascade" on the southwest side of the main mountain. This general feature of the residuals of erosion in our area may be repeatedly and clearly seen in the granitic hills of New England and might serve to dispel any doubts which remain in the minds of those students of erosion who are skeptical as to the prevailing theory of New England reliefs, for it is doubtless true that the most illuminating treatment of New England topography finds best explanatian for its mountains and higher hills in the assumption of the superior strength of their component rocks—a strength, namely, superior to that of the rock masses immediately surrounding. In a score or two of instances in Vermont and New Hampshire striking differences of relief are faithfully associated with equally striking differences of lithologic composition. Plutonic eruptives compose the mountains and generally weak schists underlie the encircling lowlands. In these examples the greater height of the hills can scarcely be due to more pronounced initial uplift during the original mountain building. When, on the other hand, differential erosion is so clear for granitic mountains like Ascutney, it seems legitimate to extend the idea to many New England residuals of schistose composition, where, as yet, full corroborative evidence as to the validity of the same assumption is not obtainable.

The view that the rocks of the classic monadnock in New Hampshire are harder than the somewhat similar rocks about that mountain certainly wins most credibility from the general agreement of that assumption with the most fruitful explanation of the New England pen.plain; but it would be a matter of considerable satisfaction to

those who have to deal in theories of land sculpture if detailed petrographic and field studies of the schist monadnocks were made with intent to test the theory of differential hardness. Perhaps a microscopic study of similarly exposed monadnock rocks and lowland rocks would enable the investigator to ascertain the amount of post-Glacial weathering which has occurred. If quantitative estimates were likewise made as to the influence of jointage, rifting, cleavage, etc., the result should be to give a more scientific basis for the discussion of the residuals of erosion than now exists. In a rough way an analogous but incomplete study of the rocks of this area has sustained the monadnock theory of the origin of Ascutney and Little Ascutney. This theory, to be sure, here scarcely needs other substantiation than the facts of composition, structure, and present relief.

DRAINAGE.

The Connecticut River flows along a belt of soft rocks parallel to their strike, and is thus a typical longitudinal valley. In no part of its course is it more clearly "adjusted" to a relatively weak zone than on the "Calciferous mica-schist" eastward of the mountain. Similarly Mill Brook follows the strike of the rocks in that gorge-like part of its course between the elbow south-southeast of Windsor and its confluence with the Connecticut. Elsewhere Mill Brook, like the stream entering the main river near Ascutneyville, belongs to the class of "superposed" streams, having sunk its channel irregularly through drift and terrace sands into the underlying schists. Short but broad valleys, located partly on schists, partly on the comparatively soft diorite, separate Little Ascutney and Ascutney Mountain proper. These valleys are also adjusted to weak zones in the rocks, and belong to the now well-recognized class of "subsequent" valleys.

But it is not easy to place the radiating drainage of the main mountain in the accepted classification of stream courses. There is nothing to show that the eruptives of the area ever reached the surface to form volcanic flows or cones; they seem rather to have consolidated in the form of a complex stock-like boss. The structure of the region shows that the radiating drainage is not the result of inheritance from the surface of a dome in the overlying schists, in which a different pattern of drainage would have predominated, namely, a more or less rectangular network of stream courses. Such a dome would not likely be able to alter seriously the directions of the streams originating either in the folding of the schists or in the process by which newer valleys would be worn out on weak belts parallel to the strike. These radiating streams can not, thus, be regarded as "superposed" through the schist blanket once overlying the stocks.

There is here, in fact, a kind of drainage which is controlled in its development by constructional processes fundamentally different from those usually considered in a systematic discussion of streams. Folding, faulting, and glacial and volcanic accumulation are examples of

processes leading to the formation of surfaces which are, in the initial stage, exposed to erosion. But there is a kind of subterranean construction to be found in the intrusion of large bodies of igneous rock, which may, in the course of time, affect the relief and drainage of a region much more conspicuously than the processes just mentioned. The uncovering, by erosion, of a boss of igneous material harder than the surrounding rock formations will necessitate either the true "superposition" of streams in the manner just suggested, but excluded, for good reasons, in the Ascutney instance, or the formation of new ones divergent, roughly speaking, from the center of the boss toward the lowlands of the less resistant formations. These latter streams are logically consequent on the intrusion and, to a greater or less extent, consequent in length and direction on the original contours and ground plan of the irruptive body. This may be true in a large way whatever the details of form in the upper surface of the igneous mass. Whether it be a regular boss with smooth profiles, or one irregularly terminated by apophyses into the overlying rock, the superior hardness of the intrusive will, in the end, tend to cause its projection, as a whole, above the soft-rock terrane; so that there will be brought about an approximation to the average original profile of the boss. There must in any case originate on its revealed surface a number of streams divergent from the central region of the boss and flowing toward the surrounding lower land.

Such streams are seen to be analogous to those which drain the retreating escarpments of tilted stratified beds—the class of "obsequent" streams as defined by Professor Davis. Obsequent streams drain the scarped front of a hard member of the stratified series and are the result of the excavation of lowlands by the lengthening and widening of valleys in an underlying softer formation. The radial drainage here considered is similarly caused by the removal of rock material less resistant to the weather than the intrusive igneous rock. At the same time, that removal means the origination of drainage "adjusted" to the soft encircling formation. The adjustment is here circumferential and centrifugal with reference to the middle point of the intrusive body, not longitudinal (parallel to the strike of a bedded formation), as in the case of those "subsequent" streams into which "obsequents" pour their waters.

The radial drainage of Ascutney is thus believed to owe its origin to the degradation of the encircling schists—a centrifugal control due to differential hardness. Located on a hard member, they are to be associated with obsequent drainage, and share with obsequent and subsequent drainage the characteristic of appearing only relatively late in the whole geographical cycle of degradation. They are also conditioned by the original form of the intrusive, and are thus consequent. To express their composite nature they may be called *subconsequent*, using a term which was first proposed by Professor Davis for what are generally coming to be called "subsequent"

streams. His abandonment of the longer for the shorter term, which was independently invented by him and by Jukes, leaves "subconsequent" open to the special use to which we propose to attach it. The prefix "sub" is especially appropriate, as it serves to indicate the necessary lack of absolute and exact control possessed by the constructional form of the intruded body over the trend of this class of streams even where they run over the igneous rock. That control will, to some extent, be imperfect on account of a variety of circumstances connected with the removal of the cover and the apophyses penetrating the cover. While subconsequent drainage is always divergent, it may be radial or elliptical where the intrusive has a circular or elliptical ground plan; or bilateral, as in the case of many batholiths and great dike-like intrusions; or, finally, irregularly divergent.

GLACIATION OF MOUNT ASCUTNEY.

The similarity of form between Mount Ascutney and other residuals in the glaciated tract of New England, on the one hand, and the residuals of Georgia and the Carolinas on the other, particularly in respect to the systems of radiating drainage seen on all slopes of the northern mountains, is suggestive of the fact, which seems borne out by many others, that glacial erosion has very slightly affected the shape of these greater reliefs of New England. The accumulating evidence of intense glacial erosion in alpine valleys, whereby hundreds or even thousands of feet of fresh rock have been quarried away by master glaciers from their rock floors, recalls the question, raised oftentimes a generation ago, as to how much material was disturbed by the great Pleistocene glaciers of North America. The answer seems again to be unequivocal that such erosive work as that carried on during Pleistocene times in the Norwegian fiords, for example, was not paralleled in New England. If it had been, we should expect Mount Ascutney, once entirely overridden by ice, to possess a somewhat definite stoss-and-lee form and to have suffered a serious change in its drainage. The radiating ravines are so deep and contain such clear evidences of glaciation in their bottoms that they can not be ascribed to post-Glacial erosion. They have not the appearance of cirques, and hence can not be ascribed to the work of local glaciers, for which, indeed, on so small a mountain, the required gathering ground is lacking. These ravines and water courses must be pre-Glacial. This being the case, the conclusion lies near to hand that the Labrador ice sheet did not approach in erosive activity the local glaciers of Switzerland, Norway, Labrador, or Alaska. The northwest, north, and northeast slopes of Ascutney would have borne the brunt of the glacial attack and perhaps suffered a more vigorous onslaught than the lowlands on account of the projection of the mountain above the general glaciated floor, but these slopes on the stoss side are as well provided with the usual radiating

stream courses as those on the south. It is highly improbable that such symmetry would persist if the Ascutney cone had been seriously affected in volume by the glacier. The same patent observation can be and has been made in many parts of northeastern America where the appropriate reliefs occur, but it is worthy of restatement in order to point out once again the mysterious contrast between the excavating power of present and past valley glaciers and of the incomparably greater Pleistocene ice caps.

The mantle of glacial drift in the area discussed is much interrupted and, in general, quite thin, so that outcrops of the bed rock are numerous. The fine terraces of the Connecticut and of Mill Brook cover some of the "Calciferous mica-schist" (Pl. I, *B*). The highest of these is 216 feet (66 meters) above low-water level of the river at Windsor. It was used by J. D. Dana as important evidence of the height to which the flooded Connecticut extended its banks in Champlain times.[a] The gneisses of the southwest portion of the area are blanketed over with the alluvium of the brook at Greenbush.

SUMMARY.

Mount Ascutney, like most of the mountains of New England, is a residual of erosion, a monadnock overlooking a dissected, rolling plateau. The relief as a whole and in its details is controlled by rock composition in a specially definite manner. Proofs of differential hardness are evident in the present topography, intrusive bodies contrasting in this respect with one another and with the adjacent schists. The drainage of the area is that of an ancient mountain system. There is clear adjustment of the streamways to soft structures, giving "longitudinal subsequent" streams and radially divergent "subconsequents." The latter occur on the main intrusive rock body, which dominates all the others through its superior strength against weathering influences and through its relatively greater volume. The discussion of this mountain, which is but one of a numerous family found in eastern North America, emphasizes once more the need of recognizing deep-seated intrusion as a constructive process no less important for certain regions than the faulting, folding, or some other initiating deformation of the earth's surface which begins a new cycle of erosion. The history of the Ascutney topography, including its drainage, begins logically and chronologically with the date of the intrusion of the Main syenite stock. The existing subconical form and the radiating stream courses of the mountain may be said to be "subconsequent" upon that constructional process of intrusion.

The general form of Ascutney was not essentially affected by the Pleistocene glaciation. A veneer of pre-Glacial weathered rock was removed and the rounding of minor points accomplished by the ice invasion, but the pre-Glacial Ascutney had practically the form of the present mountain.

[a] Am. Jour. Sci., 3d series, Vol. XXIII, 1882, p. 183.

CHAPTER II.

GENERAL DESCRIPTION OF THE SCHISTS IN THE AREA.

The fundamental rocks through which the eruptions took place naturally first demand attention. The following account of them will, however, be brief, as befits the main purpose of this paper. They consist of two conformable members, a phyllitic and a gneissic.

PHYLLITIC SERIES.

The numerous specimens collected from the phyllite indicate a tolerable uniformity in the lithological character of that rock throughout its whole extent in the neighborhood of Mount Ascutney. It is composed essentially of quartz, sericite (often partially replaced by biotite), argillaceous, chloritic, and carbonaceous material, accompanied by notable amounts of iron sulphides and titaniferous iron ore (Pl. II, *A*). Rare crystals of orthoclase and of a triclinic feldspar, equally rare grains of epidote, and perfect, minute crystals of rutile and of titanite are sporadically developed. The quartz forms interlocking grains between the sericite fibers and layers which produce the marked lamination of the rock. Straining in the quartz is at times notable and seems to be correlated with microscopic faulting in the rock as a whole. Along these incipient fault planes a further development of sericite has taken place, thus giving the rock the wavy appearance characteristic of strain-slip cleavage (Pl. II, *B*). Good examples of this phenomenon are to be found in the quarry beside Mill Pond near Windsor. Lenses and laminæ of milky quartz are very abundant and have sometimes shared in the crumbling of the phyllite, though generally they seem to have been formed posterior to its folding.

Very often through the series the argillaceous material is nearly or quite absent and we have a simple quartz-sericite-schist. An exceptionally fresh specimen of this phase, collected in the low cliffs just west of Ascutneyville (spec. 24), has been analyzed (Table I, p. 15.) It is practically a quartzite, which bears, in addition to the other essential constituent, sericite, very small amounts of orthoclase, an undetermined plagioclase, epidote, ilmenite, rutile, titanite, and a little pyrite, with probably pyrrhotite.

TABLE I.—*Analysis of quartz-sericite-schist (specimen 24) from cliffs west of Ascutneyville.*

	Per cent.
SiO_2	90.91
Al_2O_3	4.18
Fe_2O_3	0.22
FeO	1.27
MgO	0.37
CaO	0.22
Na_2O	0.77
K_2O	0.58
H_2O above 110° C.	0.74
H_2O below 110° C.	0.06
CO_2	0.18
TiO_2	0.28
ZrO_2	0.02
P_2O_5	0.05
Cl	Trace.
F	Trace.
FeS_2 and Fe_7S_8	[a] 0.11
MnO	Faint trace.
BaO	Trace.
Li_2O	Strong trace.
C	[b] 0.10
	100.06
Total S	0.056
Sp. gr	2.678

The phyllites outcrop on the edge of the upper terrace of the Connecticut River with a strike of N. 5° E. and an average dip of 50° E. (Pl. VII.)

The planes of foliation here and all across the series to the gneissic area are regarded as very closely coincident with the original bedding. Many beds of limestone from 3 inches to 2 feet (8 to 60 centimeters) in thickness are intercalated in the phyllites and are always, so far as observed, conformable with their foliation planes. C. H. Hitchcock used the foliation as expressive of true stratification and has remarked: "I believe the strata on both sides of Ascutney are monoclinal and dip easterly."[c] Farther to the west, in the monoclinal structures of the Green Mountains, patient and successful study of the actual bedding has showed a close correspondence of schistosity and true dip in the many folds overturned to the west.[d] On the other hand, there is no doubt that in other localites in this same phyllitic formation there is "striking unconformity between the planes of deposition and the fissility."[e]

[a] Note by Dr. Hillebrand, analyst: On boiling with dilute HCl, some H_2S is given off, followed by a strong and persistent odor of volatilizing sulphur, showing the decomposition of a sulphide with the formation of H_2S and the simultaneous deposition of sulphur. It is probable that both pyrite and pyrrhotite are present.

[b] Another sample gave 0.08 per cent carbon and 0.42 per cent CO_2.

[c] Geology of New Hampshire, Concord, 1877, Vol. II, p. 400.

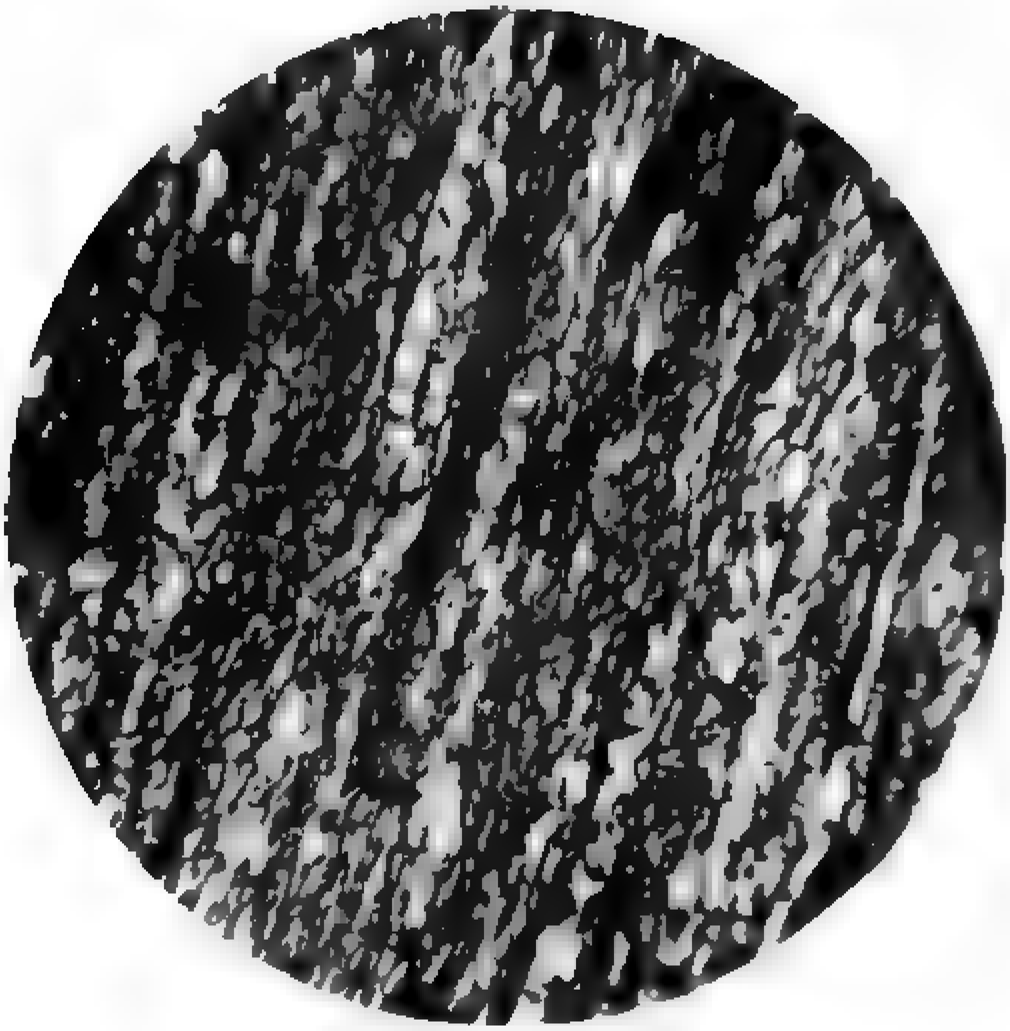
[d] See C. L. Whittle, The general structure of the main axis of the Green Mountains: Am. Jour. Sci., 3d series, Vol. XLVII, 1894, p. 347.

[e] C. H. Richardson: Proc. Am. Assoc. Adv. Sci., Boston meeting, 1898, p. 296.

PLATE II.

A, **Unaltered phyllite,** showing normal plane-parallel structure; **ordinary light,** × 20. **(See p. 14.)**

B, **Phyllite, showing** bent laminæ and strain-slip cleavage; **ordinary light,** × 20. **(See p. 14.)**



(A)

(B)

THE MERIDEN GRAVURE CO.

There is no better summary of the writer's views, obtained from but a limited study of the series in the vicinity of Ascutneyville, than that already given by Edward Hitchcock: "We have noticed no cases where the stratification and schistose structure did not essentially coincide, though often one or the other was obscure, very probably because there was a discordance of this kind, which careful study might have traced out."[a]

Westward across the strike on the north side of the mountain the dip of the phyllite is seen to steepen until the bedding shows an inclination of 75° or more to the east. These high dips occur about in the meridian passing through a point a half mile east of Brownsville, where, in places, the dip is even vertical. The strike ranges from N. 10° E. to N. 23° W., but is rarely far from its average trend, which is due north and south. The cross section on the south side of the mountain indicates a variation in the strike of from N. 15° E. to N. 20° W., with the average again practically north and south. The dip averages 60° to the east, though a rapid steepening below the granite quarries gives angles as high as 83°. The two sections of the phyllitic series thus correspond to a dynamically metamorphosed integral mass of sediments, deformed so as to present the appearance of a great thickness of conformable tilted rocks with a high dip to the east.

GNEISSIC SERIES.

West of the meridian which passes through the diorite-syenite contact appears a group of medium-grained to coarse-grained crystalline schists more varied in composition and more complex in structure than the phyllites. There is no distinct plane of junction between the two series. Both north and south of the mountain, going west, the phyllite simply assumes a more and more feldspathic character until it merges into a conformable and typical gneiss. No attempt has been made to unravel this complex, even so far as that is possible. A qualitative treatment only has been deemed sufficient for present purposes, and as a result only very slight differentiation of the gneisses is to be noted on the map.

The most abundant member of the gneissic series is a muscovite-biotite-epidote-gneiss of variable texture. It is often richly charged with scapolite. Likewise abundant are biotite-muscovite-gneiss, biotite-gneiss, muscovite-gneiss, epidote-gneiss, or mica-schists, all of which seem to be transitional into the main gneissic type. Very often the feldspars are large and the structure is that of a true augengneiss. All these types may be garnetiferous. With them are associated thin bands of beautifully crystallized hornblende-biotite-quartz-schists and epidotic hornblende-schists. The finest types of these hornblende-schists were found in a number of massive ledges on the west side of

[a] Geology of Vermont, Claremont, 1861, Vol. I, p. 476.

the road running through Greenbush, and thus outside the limits of the area mapped, but excellent sill-like occurrences may be studied just below the Crystal Cascade. Thick pods of coarsely crystalline limestone and of marble, generally charged with nests of radiating tremolite (the "wood-rock" of the quarryman), are included in the gneissic area, but again outside the immediate region under consideration. The nearest of these lenses of limestone has been rather extensively quarried for the manufacture of quicklime at Amsden, about 2 miles southwest of Little Ascutney. Sheets of now greatly weathered diabase are not uncommon in the gneisses, and the apophyses from the diorites and syenites often assume the same form.

An intrusive sheet of composition and origin quite different from that of any other rock yet studied in the area was found exposed for a length of about 500 yards (458 meters) with a strike of N. 15° W. It is terminated at the northern end by the younger rock mass of the Main syenite stock at a point about one-half mile from Crystal Cascade. The southern end of the sheet is concealed by a drift. This sheet varies from 60 to 100 feet in thickness and dips, conformably with the quartz-epidote-schist, 55° to the east. The inclusion within its mass of horses of the schist and the appearance of apophyses from it within the latter clearly prove its intrusive nature (see Pl. VII).

A gneissic structure is generally visible on weathered surfaces, though it is sometimes quite absent. The sheet rock has evidently been squeezed with the schist, and both have been broken by faults of small throw. The light-gray hand specimen itself exhibits granulation, and the extensive alteration of the old eruptive is indicated by the presence of many irregular grayish to silvery-white blotches of muscovite (specimen 175). Dark-colored minerals are not visible macroscopically. Microscopic examination shows that the crushing has been profound. Abundant granulated quartz and orthoclase, greatly bent lamellæ of plagioclase and microcline (?), and the abundant muscovite present especially characteristic proofs. Besides epidote, which appears to be a metamorphic derivative from the plagioclase, rare zircon crystals and a few grains of an iron ore complete the list of constituents. A muscovite-gneiss at the present time, this rock was doubtless of the nature af an aplitic sill before the period of dynamic metamorphism. It is of interest in representing something like the condition to which the latter eruptives would have been reduced if, since intrusion and consolidation, they had been affected by mountain building on the scale indicated by the present attitude of the schists.

It has already been noted that on both sides of the mountain the phyllite assumes from east to west a more and more gneissic character in a fairly broad north-south zone. The strike and dip in this transition zone are similar to those of the phyllites proper, and they are retained in the gneisses on the south of the dioritic stock. On the north side, however, while conformable with the phyllite near the

transition zone, the gneisses vary in strike from north and south to east and west. The average strike is about northwest to southeast. As the section is followed westward the gneisses are seen to be greatly contorted and to writhe about in the most irregular way, the angle of dip changing considerably with the strike. These structural changes are introduced so gradually in and west of the transition zone that they do not preclude the idea that the gneiss underlies the phyllites conformably. Such is believed to be the relation between the two series.

In this instance the chronological treatment of the rocks of the area has been deviated from. This has been done because the phyllites have greater stratigraphic simplicity, and dynamic metamorphism has affected them to a much smaller degree than the older crystalline schists. At the same time, the amount of light thrown on the origin of the gneisses by the brief and limited study of the phyllites is not that which would accrue from an accurate and detailed mapping of the schists far beyond the limits of the area mapped. The intimate association of the two series and the occurrence of the limestone pods in the gneiss render it highly probable that the gneiss is for the most part composed of material that was originally sedimentary. Beyond this general statement the facts obtained in the Ascutney area will not permit us to go, nor for the immediate purpose of this paper is it necessary to inquire further into the details of the history of the metamorphism.

GEOLOGIC AGE OF THE SCHISTS AND OF THE INTRUSIVE ROCKS.

Outside regions must be turned to for a solution of the difficult problem as to the age of the schists and, inferentially, as to the maximum age that may be assigned to the eruptives. The Vermont Survey Report of 1861 includes the phyllitic series in the "Calciferous mica schist," and states that this formation is overlain by clay slate which a "strong presumption" would place in the Devonian; and hence that the schist is at least Devonian, and may be older.[a] Speaking of the underlying gneiss, Edward Hitchcock wrote, "We have already made it probable that the Calciferous mica schist has been converted into gneiss from Ascutney southward. If so, whatever the age of the schist may be, that of the gneiss is the same."[b] Hitchcock left the question of age open, though he seems to have given weight to T. S. Hunt's conclusion, based on studies in the northern extension of these schists into Canada, that they are of Niagara or, at any rate, Upper Silurian age.[c] Emerson has proved that the Bernardston series of Vermont and Massachusetts is of Hamilton and Chemung age.[d] That series overlies the Calciferous mica schist, so that the latter is Lower Devonian or older.

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[a] Vol. I, p. 485.
[b] Geology of Vermont, 1861, Vol. I, p. 470.
[c] Am. Jour. Sci., 2d series, Vol. XVIII, 1854, p. 198.
[d] Idem, Vol. XL, 1890, p. 263.

Recently the detailed field observations of C. H. Richardson have afforded more definite information. He divides the Calciferous mica schist into a calcareous member, the Washington limestone, and a noncalcareous member, the Bradford schist. The latter includes the phyllitic series of the Ascutney region. Richardson correlates the Bradford schist with the Goshen schist of Emerson in Massachusetts. The Bradford schist is "flanked on the east by a band of clay slate and on the west by the Washington limestone, which in turn is flanked on the west by a band of clay slate. The two bands of slate, the Bradford schist, and the Washington limestone lie unconformably both on the east and west on a synclinal trough of the hydromica-schist, which is Huronian." His discovery of fossils in the clay slate has enabled Richardson to prove it to belong to the Lower Silurian. "The Bradford schist and Washington limestone, which have oscillated from the 'Primitive' of Zadock Thompson to the Niagara of Professor Dana, are Lower Silurian, and, more definitely, Lower Trenton."[c]

The schists had been flexed into essentially their present attitude before any considerable eruption of igneous rock took place in this area. The sheets of amphibolite and sills of aplitic material noted above have been changed both in composition and structure by the dynamic action of the tilting process. They are, however, of minor importance, and do not weaken the conclusion that the mountain-building forces had practically ceased acting before the eruptive masses of Ascutney had appeared in the main conduit. Occasionally the feldspars and biotite crystals of the rock in the oldest (gabbro-diorite) stock show considerable straining and bending, but such effects are far inferior in degree to those which would result if the diorite had undergone the enormous pressure necessitated in the folding of the sediments. The still younger intrusives show even less evidence of squeezing or dislocation since they were consolidated.

The principal intrusions are, accordingly, post-Trenton in age, and probably, if we may judge from the analogy of other granitic intrusions in the Appalachian system, post-Carboniferous and pre-Cretaceous. Nearer than that they can not as yet be more definitely dated.

SUMMARY.

The irruptives of Mount Ascutney cut a series of tilted schists assigned to horizons equivalent with that of the Bradford schist or older; i. e., they are regarded as Trenton or pre-Trenton in age. The overlying phyllites—the "Calciferous mica-schist" of the geological survey of Vermont—belong to the Bradford schist proper. While highly metamorphic and greatly deformed, the phyllites, with the interbedded quartzitic and thin limestone bands, show an apparent

[c] Proc. Am. Assoc. Adv. Sci., Vol. XLVII, 1898, p. 296.

parallelism between schistosity planes and stratification planes. Beneath this series is a conformable group of schistose rocks consisting of common mica-gneisses, epidote-gneisses, amphibolites, and crystalline limestone.

The intrusions are of later date than the last great period of rock folding which has affected the Ascutney region, and the balance of probability makes them post-Carboniferous and pre-Cretaceous in age.

CHAPTER III.

CONTACT METAMORPHISM.

THE METAMORPHIC AUREOLE.

The metamorphic aureole developed about the stocks is worthy of detailed consideration. As one approaches the contact from any side of the mountain he speedily notes plentiful evidences of the squeezing, crumpling, and fracturing of the schists, which thus have a more complex structure than they have at some distance away from the massive rocks. Especially good examples of this may be seen on the cleared spurs on the southeast side of Ascutney Mountain proper. There, as elsewhere, further proof of the energetic nature of the intrusions is to be found in the numerous apophyses sent into the bedded series and in the disruption of blocks, great and small, from the latter, often forming a "permeation area" in the eruptive masses; but the purpose of the present chapter relates not so much to the dynamics of the metamorphic action as to the mineralogical changes which have taken place in the schists.

The heat and the mineralizers accompanying the intrusions have produced alterations which are most important in the phyllites and associated limestones. On account of the well-known mineralogical stability of the gneisses and of the quartzitic bands the metamorphic effects upon these rocks have been mechanical rather than chemical or mineralogical.

The breadth of the aureole is not great in any part. Indisputable contact metamorphism has not anywhere been recognized at much over 600 feet (183 meters) from the contact, and may often be distinctly seen no more than 300 feet (91 meters) away from the same line. In the phyllitic series the metamorphic belt averages about 500 feet (154 meters) in width, and that irrespective of the attitude of the schists and irrespective of the stock nearest to which the measurement is made. The Main syenite stock has controlled the metamorphic action, although the Basic stock seems to have slightly intensified the action at the triple contacts of syenite, phyllite, and diorite. It is essentially correct to speak of the metamorphism of the phyllites as resident in one aureole produced by the intrusion of the Main stock.

CHANGES IN THE LIMESTONES.

The interbedded calcareous layers of the phyllitic series are specially sensitive to this contact transformation. Two different rock types result from the alteration of the fine-grained bluish-gray siliceous limestone, which is composed simply of calcite, quartz, and carbonaceous matter (spec. 114).

The first of these phases of recrystallization has resulted from an abundant replacement of the calcite by epidote, the other constituents remaining unchanged. This variety was found at several points in the aureole. Of the occurrences known, that farthest removed from the syenite lies about 600 feet (183 meters) from the contact at the base of the prominent 2,350-foot spur bearing east by north of the summit. A very similar phase was discovered only 3 feet (0.9 meter) from the contact at the Crystal Cascade. Here scapolite is also developed and rare grains of titanite and brownish-green hornblende are accessory (spec. 100).

The second phase is illustrated in a specimen from a field just west of the old road leading up to the quarries in the granite. The ledge from which it was taken is 450 feet (137 meters) from the contact with that intrusive. Attention was first called to it by the very noticeable roughness of the weathered surface, which betrayed the presence of some mineral in roundish masses more resistant to the weather than the other constituents (spec. 5). The fresh specimen is light gray, mottled with these subcircular, rather darker-colored, oily-looking areas about 6 millimeters in diameter and at an average distance of 1 to 2 centimeters apart. Under the microscope the areas resolve themselves into irregular aggregations of the colorless to yellowish lime-garnet (grossularite), inclosing large amounts of calcite. The occurrence is thus similar to that described by Harker and Marr in the metamorphosed limestone of the Shap Fell region in England[a] and to many others of different localities.

The garnet never shows crystal form, nor, except in rare cases, any distinct cleavage. The usual optical anomalies and zonal extinction are present. The anisotropic property is very unevenly distributed throughout the areas. It may be completely absent in one grain and give a polarization tint like that of zoisite in a contiguous individual. The double refraction shows that in some instances the areas are occupied by single poikilitic crystals of the grossularite as shown by the uniform extinction on revolving the section between crossed nicols. The same test would seem to indicate the composite character of other masses which are aggregates of small individuals. The only other change from the normal limestone is the complete disappearance of carbonaceous matter. Quartz remains in relatively high proportion and occurs with calcite as inclusions in the garnet.

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[a] Quart. Jour. Geol. Soc., Vol. XLVII, 1891, p. 311.

METAMORPHISM OF THE PHYLLITES.

The average normal phyllite is, as we have seen, considerably more argillaceous than the quartzitic schist analyzed (see Table I, p. 15). The minerals characterizing the rocks resulting from the alteration are, as a rule, those which might be expected from mere recrystallization of the original constituents, viz, quartz, sericite, chlorite, clayey matter, iron ores, and sulphides.

There is no definite succession of zones of metamorphic action, either of color, structure, or mineral aggregation, as in the classic region of Barr Andlau. The macroscopic changes are simple and uniform in all parts of the aureole. Quartz veins and eyes become more numerous as the contact is approached; the lamination of the schist becomes, at the same time, more and more lost, and the rock takes on an increasingly compact and indurated look. Yet even at the contact itself the presence of quartzose laminæ in the original phyllite often entails a partial preservation of the schistose structure. Occasionally obscure spotted and knotted areas are found, but they are not conspicuous nor are they arranged in any fixed order.

The general mineralogical changes may be summarized as comprising a progressive disappearance of sericite, quartz, and argillaceous substance and a corresponding development of biotite, red garnet, cordierite, pleonaste, corundum, and sillimanite. These new minerals naturally occur most abundantly and in larger crystals near the contact than farther out in the aureole. In tracing these changes, the attempt was made to collect specimens along the strike, thus inviting, though, on account of the variability and disturbed character of the schist and because of the lack of sufficient outcrops, not entirely securing, the maximum of certainty as to just how great has been the influence of this local metamorphism on lithological units. Three fairly representative sections of the contact zone were made in this way; perhaps no better means of describing the phenomena of the zone can be adopted than to consider each of the sections somewhat in detail.

SERIES A OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

The first of these sections in the aureole is noted on the geological map as occurring at the syenite contact on the north side of the mountain; the set of specimens collected there may be called "Series A." For ease of reference each of the following paragraphs relating to the description of the specimens is preceded by a number indicating the distance from the contact of the specimen to which that paragraph refers.

500 feet (154 meters).—Five hundred feet from the contact the phyllite shows some crumpling and other evidences of disturbances; so far as known, however, no new mineral has been developed at that distance.

400 feet (*122 meters*).—One hundred feet nearer, the sericite is largely replaced by an indeterminable chloritic substance, but it is probable that this phase also is original.

300 feet (*91 meters*).—Somewhere within the next 100 feet measured toward the contact there is a comparatively abrupt appearance of true contact minerals, coupled with a decided loss of the original fissility of the rock (spec. 129). At 300 feet from the syenite, there is a partial replacement of the argillaceous and chloritic material and of quartz by cordierite, while the whole rock is filled with a swarm of extremely minute, light-green, isotropic grains with high, single refraction. An occasional grain of epidote lies with the iron sulphides (pyrite and probably pyrrhotite) in the planes of schistosity, which are still to be seen, both macroscopically and in the thin section.

250 feet (*77 meters*).—Fifty feet nearer, the metamorphism has affected the whole rock. Its original dark-gray color has now a bluish cast (spec. 128). A high degree of induration with a corresponding loss of lamination and an increase in the specific gravity are characteristic. A peculiar feature of this hand specimen is the presence of numerous roundish and isolated areas of what can be discerned, even macroscopically, to be granitic aggregates of quartz, feldspar, and other minerals embedded in the general rock matrix. They bear a relation to the transformed schist analogous to that of a miarole to its igneous host, and, for lack of a better term, they may be called "pseudo-miaroles." Microscopic examination shows that the basis of the rock is now cordierite occurring in interlocking individuals 2 to 3 millimeters in diameter. It is always poikilitic either from the mutual intergrowth of several crystals of its own substance or from the swarms of mineral inclusions of different sorts (the "sieve-structure" of Salomon). Those inclusions are the same as the other constituents of the hornfels, viz, numerous small shreds of intensely pleochroic brown biotite, abundant, irregular grains of deep-green spinel, pyrite, pyrrhotite, ilmenite, tourmaline of brown and yellow tones, quartz, and minute black, probably carbonaceous particles.

These various inclusions cloud the whole thin section except in the more quartzose laminæ, which are doubtless residual from the original rock, and in the pseudo-miaroles. They are also lacking in the numerous stringers of quartz which traverse the schist. Probably the recrystallization of the schist was complete before the quartz was laid down in the veinules and the pseudo-miaroles were filled with their granitic contents. The latter consists of the minerals characteristic of the adjacent syenite—microperthite, cryptoperthite, quartz, brown alkaline hornblende, and rare zircons. With them is often associated a pale-reddish garnet averaging about 1 millimeter in diameter. The quartz is so abundant as to give the hypidiomorphic-

granular aggregate the composition of a true granite. These pseudo-miaroles when round in outline measure from 3 to 5 millimeters in diameter; when, less often, they are elongated in the section they measure from 5 to 10 millimeters in length. They are not connected with one another or with distinct apophysal veins from the syenite, but are completely surrounded by the cordieritic matrix. It looks as if there had been a shrinkage of volume in the schist during its recrystallization and the resulting cavities were subsequently filled with the granitic substance by a pneumatolytic process. We have, whatever be the explanation, a striking case of feldspathization of schist by an intrusive granitic rock wherein the channels of approach of the feldspathic material were of submicroscopic dimensions. The deep-green spinel is pleonaste, which is now of increasing importance as we go toward the eruptive rock. It was this mineral that was seen at the 300-foot distance, where the very small grains were indeterminable. Similar fine material is present here, but it grades up into larger individuals which are undoubtedly pleonaste. Here, too, the pleonaste has an interesting localized distribution, being grouped in roundish clusters composed of many crystals. In one case the whole of one well-marked cluster about 0.3 of a millimeter in diameter is included in a single crystal of cordierite. The spinel is usually without crystal form and occurs as drop-like bodies. It is worthy of note that not only in this case, but in all parts of the aureole, pleonaste and the metamorphic biotite are in reciprocal relation to each other; where one is abundant the other, relatively, is rare. This fact correlates with the observation of Lacroix that spinel is a common product of the alteration of mica in inclusions caught up in lavas,[a] and with our own observation that, close to the contact, where we should expect the more stable products of metamorphism, the biotite is often completely replaced by pleonaste.

150 feet (46 meters).—One hundred feet nearer the contact the schist is macroscopically similar to the rock found at 250 feet in its compactness, lack of pronounced schistosity, and bluish-gray color, but lacks the pseudo-miaroles and is more strongly charged with the red garnet (spec. 127). Mineralogically the most important difference is found in the entrance of corundum as a new metamorphic constituent. This occurs as irregular colorless grains, often grouped in clusters about ilmenite in the form of a mantle. This new mineral is in small amount and its description may be deferred for better occurrences at other localities. Cordierite again composes most of the schist. It has here, too, the pleochroic halos found about inclusions, as well as other usual features. Pleonaste, with a clustering habit, is comparatively abundant, and biotite is rare. The garnets appear in large individuals, showing characteristic cleavage and inclusions, and also in the form of well-crystallized minute dodecahedrons without inclusions or cleavage.

[a] Les enclaves des roches volcaniques, Macon, 1893, p. 589.

Many of the larger crystals form the centers of eyes and are then wrapped about by mica plates. Generally, however, the garnet is surrounded by a clear zone of quartz and cordierite, unaccompanied by iron compounds, which have either been used to build up the garnet or are included in zones within that mineral. Though the pseudomiaroles are absent, there is evidence of some feldspathization of the schist. Occasional crystals of microperthite may be discerned in the thin section. They are products of late crystallization, as they are intersertally related to the cordierite; like the feldspars of the pseudomiaroles, they are free from inclusions of pleonaste, etc.

100 feet (31 meters.)—A specimen (No. 126) taken from a ledge 100 feet from the contact, seems in several respects to show a local exception to the general effect of metamorphism on the phyllites. Biotite is once more developed in profusion, while pleonaste is quite subordinate. Corundum is absent. Cordierite is again the principal constituent and acts as host to the pleonaste clusters. The iron sulphides are conspicuous in the hand specimen. Dr. Hillebrand remarks:

On boiling the powdered rock with dilute hydrochloric acid considerable H_2S is evolved and sulphur is set free, as can be plainly perceived by the strong smell of volatilizing sulphur accompanying that of H_2S. The decomposition begins at a moderate heat. After a time the evolution of the H_2S ceases and the smell of sulphur is no longer noticeable, and there is then found only one-third of the total sulphur left in the residue, presumably wholly as pyrite. The rest of the sulphide is magnetic and, dissolving readily in HCl with the evolution of H_2S, may be considered as quite certainly pyrrhotite.

The feldspar is much increased in amount, is notably microperthitic, and occurs in the same relations as in the last specimen described. For the first time, the feldspar shows the Carlsbad twins characteristic of the microperthite of the syenites. A chemical analysis has been made of this phase (Table II, col. 1). As a whole it corresponds to the analysis of a phyllite rich in argillaceous material. The soda is to be ascribed mainly to the feldspar, and is thus believed to have been introduced by hydrothermal action. On the supposition that all the sulphide exists as pyrite, the proportions of the iron compounds would be—

	Per cent.
Fe_2O_3	0.03
FeO	6.41
FeS_2	0.58

If two-thirds of the sulphide is pyrrhotite, these compounds should be recalculated to the following proportions:

	Per cent.
Fe_2O_3	0.30
FeO	6.00
FeS_2	0.19
Fe_7S_8	0.53

The latter proportions are, for the reason already noted, believed to be more nearly correct and are accordingly entered in the total analysis. The carbon percentage is extremely variable, corresponding to the irregular distribution of the coaly matter in the schist. One independent determination gave 0.03 per cent carbon instead of 0.40 per cent, as found for the rock fragment analyzed completely. Two analyses of typical cordierite-mica-hornfels from southern Carinthia (Table II, cols. 3 and 4), show a rather strong similarity to that of the Ascutney rock.

50 feet (*15.5 meters*).—Fifty feet from the contact a specimen (No. 125) was collected that showed a reversion to the normal sequence of the mineral occurrences as the contact is approached. The pleonaste once more largely supplants the biotite and is, in fact, more abundant than ever. It clouds the whole of the thin section, though there is a tendency toward a grouping along planes apparently representing the original schistosity. Corundum and tourmaline, like the biotite, occur but sparingly. The schist is strongly impregnated with small quartz veins and with lenses 1 to 2 millimeters in thickness, composed of quartz, microperthite, and brown biotite. The evidence is not so clear as in the case of the pseudo-miaroles that these granite lenses are not actually connected with one another and with the stock rock, but it is highly probable that both types of the granitic aggregates are to be referred to the same pneumatolytic origin.

25 feet (*8 meters*).—Halfway to the contact the rock is still the massive dark bluish-gray heavy hornfels, hardly to be distinguished in the hand specimen from the altered schist collected from the 200 or more feet of section over which we have just passed (spec. 124). A notable difference from the hornfels at 50 feet consists in the abundance of corundum, which is even more plentiful than the pleonaste. Cordierite is here again the chief constituent. While it presents the usual poikilitic interlocking habit, it sometimes has definite crystal form, with the common hexagonal sections from the base and rectangular sections from the prism. Biotite is an accessory, but tourmaline has disappeared and does not reappear between this point and the syenite. Microperthite occurs in intersertal contact with the cordierite, but is only a rather rare accessory. Besides ilmenite or titaniferous magnetite, the iron compounds include both pyrite and pyrrhotite. The test for the occurrence of the latter mineral and the method of its determination in amount are the same as has been outlined above. The strong basicity of the hornfels is noteworthy, as well as the high content of alumina. The latter easily explains the richness of the rock in corundum[a] (see Table II, col. 2).

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[a] Cf J. Morozewicz, Experimentelle Untersuchungen über die Bildung der Minerale im Magma: Tscher. Min und Petrog. Mitth., Vol. XVIII, 1898. p. 57.

TABLE II.—*Analyses of cordierite-hornfels.*

	1.	2.	3.	4.
SiO_2	58.35	45.30	55.68	56.88
TiO_2	0.87	1.48		
Al_2O_3	21.30	30.51	21.91	20.86
Fe_2O_3	0.30	0.24	2.63	2.66
FeO	6.00	8.80	6.90	4.54
MgO	2.10	3.11	3.57	3.15
CaO	0.85	0.90	0.89	1.29
Na_2O	1.60	1.65	1.01	0.91
K_2O	5.63	4.84	6.34	7.49
H_2O above 110° C.	[a] 0.86	[a] 1.05	[a] 1.41	[a] 2.36
H_2O below 110° C.	0.31	0.26	----------	----------
CO_2	None.	Trace?	----------	----------
P_2O_5	0.18	0.12	----------	----------
SO^3	None.	0.04	----------	----------
Cl	0.03	0.04	----------	----------
F	Undet.	0.04	----------	----------
FeS_2	0.19	0.36	----------	----------
Fe_7S_8	0.53	0.96	----------	----------
NiO, CoO	0.03	0.02	----------	----------
MnO	0.13	0.20	----------	----------
BaO	0.05	0.03	----------	----------
SrO	Trace.	Trace.	----------	----------
Li_2O	Strong tr.	Strong tr.	----------	----------
CuO	Trace.	?	----------	----------
C	[b] 0.40	[c] 0.17	----------	----------
	99.71	100.12	100.34	100.14
O=F.Cl	----------	0.02		
		100.10		
Total S	0.31	0.19		
Sp. gr	2.673	2.835		

[a] Loss on ignition.
[b] Another sample gave 0.03 per cent carbon and no CO_2.
[c] Another sample gave 0.03 per cent carbon and 0.04 per cent CO_2.

1. Cordierite-biotite-microperthite-hornfels, a phase of the exomorphic zone 100 feet (31 meters) from the contact, north side, Ascutney Mountain; analysis by Hillebrand.

2. Cordierite-corundum-pleonaste-hornfels, taken from the same cross section of the exomorphic zone as No. 1, 25 feet (8 meters) from the contact; analysis by Hillebrand.

3. Cordierite-biotite-orthoclase-hornfels, Schaida, S. Carinthia; analysis by Graber, Jahrb. der K.-k. geol. Reichsanst., 1897. Vol. XLVII, p. 290.

4. Cordierite-biotite-plagioclase-hornfels, M. Doja, S. Carinthia; analysis by Von Zeynek. See Graber, ibid., p. 290.

6 feet and 1 foot (1.8 meters and 0.3 meter).—A specimen taken at a point 6 feet from the contact (spec. 123), and another taken from a point only 1 foot from it (spec. 122), are very similar to each other and to the phase just described. There is, however, a decrease in corundum and an increase in pleonaste, which now possesses perfect crystal form. The octahedra are excellently developed, and are furthermore interesting, as they show the octahedral cleavage, which is seldom seen in rock-forming occurrences. The clustering habit of the pleonaste is strongly marked in both specimens. Corundum often appears as a core, about which the concentration of pleonaste took place. In other cases, the grouping is wholly in quartz crystals in a manner similar to that already noted for the clusters in cordierite.

This study of the cross section of the aureole may be summarized in tabular form as follows:

Summary of cross section of series A of metamorphic aureole.

Distance from the contact.		Compound name of aureole phase, showing its essential constitution.	Accessory and subordinate mineral constituents.
Feet.	*Meters.*		
600	183	Unaltered argillaceous phyllite	Pyrite, pyrrhotite (?), ilmenite, carbonaceous matter.
500	154	The same, crumpled	Do.
400	122	Crumpled chloritic phyllite	Do.
300	91	Cordierite-quartz-hornfels	Biotite, pleonaste, epidote, pyrrhotite, pyrite, ilmenite, carbon.
250	77	Pseudo - miarolitic cordierite-biotite-quartz-microperthite-hornfels.	Pyrite, pyrrhotite, ilmenite, carbon, tourmaline, garnet, hornblende, zircon.
150	46	Cordierite - garnet - pleonaste-quartz-hornfels.	Pyrite, pyrrhotite, corundum, ilmenite, carbon.
100	31	Cordierite - biotite - microperthite-hornfels.	Pyrite, pyrrhotite, pleonaste, carbon (graphite ?), ilmenite.
50	15.5	Cordierite - pleonaste - microperthite-hornfels.	Pyrrhotite, pyrite, biotite, ilmenite, carbon (graphite ?), tourmaline.
25	8	Cordierite-corundum-pleonaste-hornfels.	Biotite, microperthite, pyrrhotite, pyrite, ilmenite, carbon.
6 and 1	1.8 and 0.3	Cordierite-pleonaste-corundum-hornfels.	Do.

SERIES B OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

A second suite of specimens was collected from a section across the metamorphosed belt just south of Brownsville. The aureole is here at least 600 feet wide, the relatively greater breadth being probably due to the proximity of the diorite as well as the syenite. The effects produced by the intrusives are practically the same as in Series A.

600 feet (183 meters).—Six hundred feet from the contact along the strike and 500 feet across it (spec. 136), garnets, tourmaline, corundum, and a little cordierite are already found in the phyllite, which, in its unaltered phase, is more quartzose than in Series A. The quartz preserves much of its original importance; it is charged to a remarkable degree with liquid inclusions, often containing gas bubbles. Biotite is present, and is also doubtless inherited from the original schist. Rare epidote is accessory. No feldspar is recognizable. Certain colorless grains with high single and low double refraction have the appearance of andalusite, but its presence could not be proved on account of the small size of the individuals.

300 feet (91 meters).—Three hundred feet from the contact pleonaste appears as small disseminated grains for the first time (spec. 135).

100 feet (31 meters).—One hundred feet from the contact the schistose structure is no longer visible macroscopically, though it appears in the thin section (spec. 134). The biotite assumes a concretionary rather than a plane-parallel arrangement. The increased importance of cordierite and the entrance of a few needles of sillimanite are the other chief points of difference from the last locality.

45 feet (14 meters).—At 45 feet pleonaste and corundum are quite prominent, both in abundance and in size of the individuals (spec. 133). Sillimanite increases in quantity. Andalusite is, as before, doubtfully present.

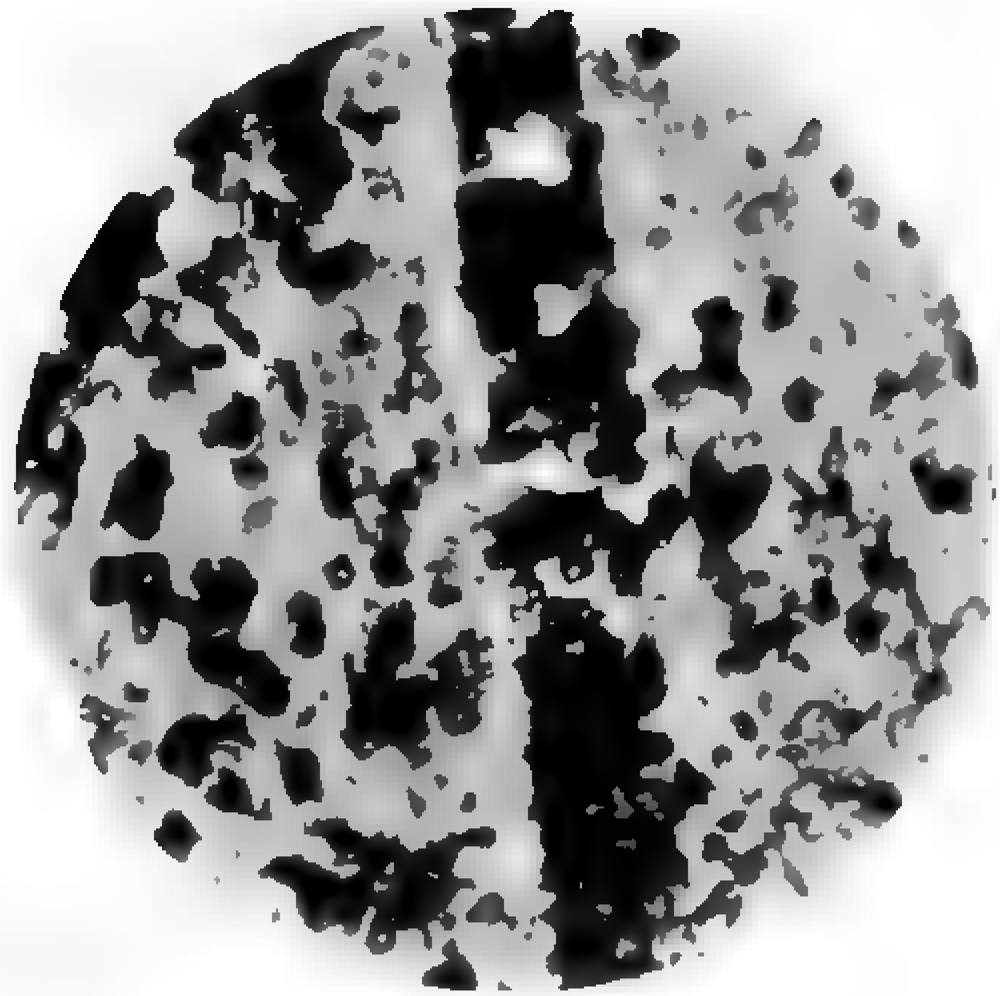
15 feet (5 meters).—At 15 feet, tourmaline is added to the list of essentials (spec. 132). The pleonaste has two types of aggregation. Besides appearing on the familiar clusters, it accumulates in long strings, which reach 2 millimeters or more in length and have a uniform breadth of about 0.1 millimeter, reminding one of the linear development of chlorite in the classic desmosite (Pl. III, *A*). This second kind of aggregation does not seem to have any fixed relation to single individuals of other constituents, and the masses of pleonaste pierce the rock in all directions. Again, this mineral is inclosed by the cordierite in a way not observed elsewhere in the aureole. Numerous rectangular grains of spinel may be arranged with their longer axes parallel to the chief axis of the cordierite host. Idiomorphic cordierite also incloses prisms of tourmaline with a similar orientation. Corundum is first seen here to assume a crystal form. Sillimanite is a common accessory.

5 feet (1.5 meters).—A specimen (No. 131) taken only 5 feet from the contact shows a rarity of metamorphic minerals which can only be

PLATE III.

A, Hornfels containing abundant pleonaste (black, of high relief) and corundum (white, of high relief) in a matrix composed chiefly of cordierite (a characteristic linear aggregate of pleonaste is conspicuous): ordinary light, × 12. (See p. 39.) Compare with Pl. II, *A* and *B*, illustrating the same phyllite from which this hornfels has been produced by contact metamorphism.

B, Thin section of quartz-bearing hornblende-biotite diorite, showing an apatite crystal inclosing a core of brown glass; ordinary light, × 50.



(A)

(B)

THE MERIDEN GRAVURE CO.

explained as characterizing a phase of the schist which was originally less richly charged with the argillaceous material that has elsewhere yielded, under the metamorphic process, the minerals above mentioned. The schistose structure is reverted to; garnet, pleonaste, corundum, and tourmaline are present, but are very subordinate and confined to the structure planes. Intersertal microperthite forms an accessory· it shows occasionally the Carlsbad twinning.

At the contact there is the same relative poverty in metamorphic products and probably for a similar reason to that adduced for the last phase (spec. 130). The rock is a compact mass of quartz, chloritized biotite, and pleonaste, with ilmenite, tourmaline, cordierite, and corundum as accessories.

SERIES C OF SPECIMENS FROM THE METAMORPHIC AUREOLE.

A third suite of specimens illustrating the contact zone was collected on the south side of the mountain. The phenomena are essentially similar to those in Series A. It would be unprofitable to give a detailed description of them, as it would be in the nature of repetition. The perfection of the crystallization of corundum is, however, worthy of special note. Within the belt 10 feet (3 meters) or more, measured out from the contact, it is an abundant essential constituent of the rock. Both basal and prismatic sections of the idiomorphic and granular crystals exhibit cores of vivid blue in the otherwise colorless mineral. Each of these cores is oriented with the longer axis parallel to the chief axis of the corundum individual. Rotated over the polarizer alone, the basal section shows no change of color; in other sections a striking pleochroism, from deep blue to colorless, is characteristic.

COMPARISON OF THE METAMORPHIC EFFECTS.

The constant nature of the metamorphism is indicated not only by the correspondence of these three series of specimens, but also by many specimens collected from points isolated in the contact zone and not connected in the serial arrangement of a cross section. Wherever the comparison could be fairly instituted, the alteration of the phyllitic rocks was seen to be of the same character, whether produced by syenite, granite, or gabbro-diorite. It is another illustration of a now familiar fact—that so widely divergent intrusive types as granite, syenite, diorite, diabases, and peridotite may form similar types of hornfels.[a]

The general order of the metamorphic effects to be observed as one approaches the contact may be stated as follows:

At 500 feet or less from the contact there begins to be apparent a distinct loss of schistosity in the phyllite. The rock gains in massiveness and in specific gravity. The extent of these changes, as of all

[a] Cf. Lacroix, Comptes Rendus, 18 févr., 1895.

the others, is manifestly controlled by the nature of the particular phyllitic band studied. The dominant mineralogical essential of the aureole is cordierite, which appears suddenly and abundantly in the outer part of the aureole. Second in importance to that mineral is pleonaste, assuming greater quantitative importance and greater size and perfection of crystal form in its individuals as the contact is neared. Metamorphic biotite is likewise abundant. Its increase means, as a rule, a decrease of pleonaste in that particular phase. Corundum behaves like the spinel in its progressive development toward the contact, but appears later in the section. Sillimanite is confined to the inner part of the zone, but is never abundant. Garnet, tourmaline, and andalusite (?) are sporadic, appearing and disappearing irregularly in the cross section, though more likely to appear at its inner extremity.

Feldspathization characterizes the aureole as far, at least, as 300 feet (91 meters) from the intrusive. It is highly probable, however, from the evidence of the hornfels analyses and of the microscopic examination, that the transfer of material from the stock magmas to their country rock is but subordinate in quantity. The mere heat of the intrusion would doubtless have been sufficient to produce some of the more important new minerals. Cordierite and spinel in abundance have been formed in coal-bearing mica-slates (schists) through the melting up of the slates during the combustion of the coal.[a] These minerals have also been observed to be the result of the alteration of the micaceous inclusions caught up by volcanic flows. The question as to just how much material has been added to the schists, either as alkaline silicate or in other form, can, however, not be satisfactorily and finally discussed until the same phyllitic band has been followed across the aureole and analyses been made from that band where it is unaltered as well as where it has been strongly metamorphosed. So far it has proved apparently impossible to follow any one band across the whole zone. The only analysis yet made of the unaltered schist relates to a quartzitic phase outcropping at a distance from the mountain (see Table I). If all the soda and potash in even that phase were to enter into the proper combinations with the alumina and silica as much as ten per cent or thereabouts of alkaline feldspar would result. The belief that feldspathization has really occurred would thus be more strongly upheld by the peculiar nature of the actual microperthitic intergrowth, so similar in every respect with the feldspar of the adjacent syenite, and by the nonoccurrence of that intergrowth in the phyllite outside the aureole, rather than by the evidence derived from the analysis of an unaltered phyllite more argillaceous than the quartzitic phase.

A list of the metamorphic constituents of the aureole, arranged in the relative order of abundance as nearly as may be by mere inspection of thin sections, may complete this brief summary.

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[a] Lacroix, Les enclaves des roches volcaniques, Macon, 1893, p. 577.

List of metamorphic constituents of the aureole.

IN THE LIMESTONES.

Epidote.
Grossularite.
Scapolite.
Hornblende.
Titanite.

IN THE PHYLLITES.

Cordierite.
Biotite.
Pleonaste.
Corundum.
Lime-iron garnet.
Sillimanite.
Pyrrhotite.
Pyrite.
Tourmaline.
Andalusite (?).
Graphite (?).

Microperthite Quartz Brown hornblende Biotite	Introduced substance of the "pseudo-miaroles" and intersertal areas.

There are strong resemblances between this list and those made out by G. H. Williams at the Cruger's section (diorites of the Cortlandt series metamorphosing biotite-muscovite schists),[a] and by Teller and Von John in the Tyrol (norites and diorites cutting phyllites and gneisses).[b]

SUMMARY.

The schists display unequal effects of contact metamorphism where they lie in contact with the intrusive bodies. As was to be expected, the gneisses are much the more stable and exhibit little mineralogical change even close to the eruptive contacts, but the abundant argillaceous material of the phyllites has been extensively recrystallized into a well-defined zone of hornfels. Cordierite, pleonaste, biotite, garnet, corundum, and epidote form the chief secondary minerals thus developed. The limestone bands have richly yielded grossularite and epidote in the same contact zone. Repeated occurrences of interstitial microperthitic feldspar lead to the conclusion that, during the intrusion of the syenites and granite, feldspathization of the phyllitic country rock has taken place.

[a] Am. Jour. Sci., 3d series, Vol. XXXVI. 1888, p. 254.
[b] Jahrbuch K.-k. geol. Reichsanstalt, Vol. XXXII, 1882, pp. 655 and ff.

CHAPTER IV.

THE ERUPTIVE ROCKS.

GENERAL TABLE AND CORRELATION.

It was thus into a series of tilted metamorphosed sediments that the irruptions with which we are here particularly concerned began (see Pl. VII). The variety, as well as the relative ages of the resulting rock bodies, is indicated in the accompanying table, which gives a summary statement of the succession, from the oldest to the youngest intrusive:

TABLE III.—*Rock bodies resulting from the irruptions.*

(From oldest to youngest.)

A. Basic stock of five chief phases, viz:
- a. Augite-gabbro.
- b. Hornblende-biotite-augite-gabbro.
- c. Biotite-hornblende-diorite.
- d. Biotite-augite-hornblende-diorite.
- e. Orthoclase-microperthite-bearing hornblende-biotite-diorite (containing basic segregations) = acid essexite.

This stock is cut by—
1. Reticulate intrusions (forming intrusion-breccias) of augite-biotite-diorite with and without essential hornblende.
2. Dikes of "windsorite," the alkaline equivalent of granodiorite.
3. Nordmarkite porphyry stock-like dike of Little Ascutney (bearing basic segregations and cut by Nos. 6 and 7).
4. Main stock (B) of Ascutney Mountain and its apophyses.
5. Pulaskite (quartzless biotite-nordmarkite) stock of Pierson Peak.
6. Hornblende-paisanite dike (cut by camptonites).
7. Camptonite dikes.
8. Diabase dikes (?).

B. Main stock of Ascutney Mountain, of four chief phases, viz:
- f. Hornblende-biotite-nordmarkite of granitic structure (bearing basic segregations).
- g. Hornblende-biotite-augite-nordmarkite of porphyritic structure (bearing basic segregations).
- h. Alkaline granites without essential bisilicates.
- i. Monzonite.

This stock is cut by—

9. Hornblende paisanite dikes.
10. Camptonite dikes.
11. Diabase dikes.
12. Common muscovite aplite.
13. Stock C.

C. Stock of alkaline biotite-granite (bearing basic segregations).

A general correlation of these intrusives in terms of eruptive periods and composition may be made in the form of a second table:

First eruptive period	A (a, b, c, d, e)	Gabbro-dioritic magma.[a]
Second eruptive period	1 and 2	
Third eruptive period	B (f, g, h, i), 3 and 5	Syenitic magma.
Fourth eruptive period	6 and 9	
Fifth eruptive period	C and 12	Granitic magma and aplite.
Sixth eruptive period	7 and 10, 8 and 11	Lamprophyres.

The reference of the individual intrusives to the different magmas or their derivatives is indisputable except in the case of No. 2, which is intermediate both in composition and in geological age between the Basic stock and the Main syenite stock. The reference to the different eruptive periods as stated in the table is to some extent arbitrary. The stocks A, B, and C certainly followed one another in the order named. As the map shows, the conduit through which the substantial contributions to the whole mass were made migrated from west to east. The intimate field relations of A, 1 and 2, seem to show that all three antedate the syenites. Nos. 1 and 2 cut A and are probably older than B or its equivalent. Nos. 3 and 5 are correlated with B on the ground of close mineralogical and structural similarity; they are clearly older than Nos. 6 and 9, which were probably not strictly contemporaneous. Though stock C also cuts B, it is probably not contemporaneous with No. 6 or No. 9. It is probable, though not proved, that stock B is older than the lamprophyres, which are certainly younger than all the syenitic intrusions.

In all the stocks and in many dikes of the area, nodular masses of segregational basic materials occur. They are most common in the syenites, less so in the alkaline granite stock, and comparatively rare in the diorities. These nodules were early noted and described by Edward Hitchcock and others, and remarked for their extreme abundance. They will be treated of in some detail in the following pages in connection with the petrographical description of their parent rocks.

It will be seen that among the petrographical methods employed, those for the determination of the feldspars have been in the most constant requisition. In order to avoid repetition and a certain degree of monotony in the description, the actual readings on which the determinations of the various species have been based are, as a rule, not given in the text. In general, several independent methods have been used for each determination. Examples of these are noted in the discussion of the rocks composing the largest stocks examined. In the compound names of some of the rock types, as well as in the tables of mineralogical composition, the mineral constituents are entered in the order of decreasing importance in their respective rocks.

[a] A magma intermediate in average composition between gabbro and diorite. The adjective is not derived from the term "gabbro-diorite," as used by G. H. Williams or by Törnebohm.

GABBROS, DIORITES, AND RELATED ROCKS.

BASIC STOCK; GABBRO AND DIORITE PHASES.

The oldest of the intrusives illustrates the common characteristic of basic stocks in exhibiting considerable variation of composition, structure, color, and texture in its rock types. A large number of thin sections were made from specimens collected in all parts of the stock. They show that its material occurs in the form of five different phases, repeatedly occurring in more or less typical form, and connected with one another by transitions. All five seem to have been differentiated from the product of a single intrusion. That we have here to do with an eruptive of a truly exotic nature is abundantly proved at almost any point of the schist contact. Both to the north and to the south of Little Ascutney excellent examples of intrusive dikes and sills, plainly apophysal from the massive rock, are to be found cutting the gneisses. The horses of schistose rock are so abundant at many contacts as to make up veritable flow breccias, and fragments are occasionally found several hundred yards from the contact.

Phase d is the one rock type from the Basic stock which has been chemically analyzed. It is somewhat more acid than the average type, but it was selected on account of its relative freshness. The specimen analyzed (Table IV, col. 1) was taken from some blasted ledges about 100 yards north of Mr. Pierson's house, on the notch road between the two Ascutneys. It is a fairly coarse-grained dark bluish-gray quartz-diorite of typical hypidiomorphic granular structure, in which the essential dark-colored silicates are biotite and a diopsidic augite with subordinate brown hornblende (spec. 35).

The feldspar of the rock is almost always multiple-twinned, following the albite law, more rarely the pericline law. The very common association of albite and Carlsbad twinning in the slide makes it possible to determine the feldspar with a high degree of accuracy. In addition, Becke's method of differential single refraction, the reading of extinctions on cleavage pieces and on sections cut parallel to the bissectrices, and the principle of equal illumination in the zoned individuals agreed well in establishing the average mixture of the soda and lime molecules as one slightly more acid than the basic oligoclase, $Ab_2\ An_1$. Yet single individuals may vary from the acid oligoclase $Ab_4\ An_1$ to bytownite $Ab_1\ An_4$. Zoned crystals are common. The cores range from $Ab_1\ An_1$ to $Ab_2\ An_1$, with an average close to the andesine $Ab_4\ An_3$, while the outer zones seem to be invariably more acid, with an upper limit at the acid oligoclase $Ab_4\ An_1$.

The tolerably high percentage of potash in the analysis leads one to suspect a potash feldspar, but diligent search has so far failed to establish the presence of either orthoclase or microcline. The refraction of the rare untwinned individuals was carefully compared in a number of slides with the refraction of quartz and undoubted plagio-

clase, and showed, often with the corroboration of convergent light, that these untwinned individuals are likewise soda-lime feldspars averaging basic oligoclase. The determination of orthoclase in the rock powder is impossible because the basic oligoclases and acid andesines occur in such profusion. The potash of the analysis must, then, be referred primarily to the biotite, and, in a notable degree, to isomorphic mixture with the soda-lime feldspar. That there must be some potash outside of the biotite is not to be doubted, for, granting the high proportion of 10 per cent of potash in the biotite, and crediting that mineral with all the oxide, there must be at least 23.4 per cent biotite in the rock. Inspection shows that even that minimum proportion of the mica is not represented, although it is next the feldspar in abundance. It has the usual properties of biotite from normal granitic rocks—powerful pleochroism and absorption in brown and yellow tones, extremely small optical angle, and parallel extinction.

The augite is crystallized both alone and in the form of intergrowths with hornblende. In both cases the habit of the mineral is that of common diopsidic, colorless to pale greenish, allotriomorphic individuals from 1 to 5 millimeters in diameter. A third cleavage parallel to (100) occurs in a few sections. Twinning parallel to (001) is not rare. Pleochroism is absent. The alteration is largely confined to chloritization, but paramorphic changes to a uralitic amphibole are common.

The brown hornblende almost invariably forms intergrowths, either irregular or oriented in parallel fashion with augite. In all cases the mineral is doubtless primary. The pleochroism is as follows:

a. Pale grayish yellow.

b. Greenish brown with a tinge of olive (medium absorption).

c. Brown (medium to strong absorption).

c>**b**>**a**.

The prismatic angle is 55° 32′ (average of measurements on eight cleavage pieces). The extinction on (110) is about 12° 30′, and on (010) about 15°. It is seen that the mineral belongs to a common variety of amphibole.

Quartz forms allotriomorphic, cementing grains which represent the last stage in the crystallization of the rock. It is never present in large amount. Gas and liquid inclusions, often simulating negative crystals in form, are common, particularly in the coarser-grained specimens of the rock.

Apatite needles and larger crystals are abundant. A characteristic feature of this accessory is the common inclusion, in the form of elongated cores, of isotropic, probably glass, bodies of a deep-brown color (Pl. III, *B*.)

Ilmenite or titaniferous magnetite and primary titanite with weak pleochroism are important accessories. Large zircon crystals and occasional grains of pyrite complete the list of accessories.

The structure is hydiomorphic-granular. The feldspar is often

idiomorphic against both augite and quartz. The biotite is always idiomorphic against quartz, rarely against feldspar, and may inclose all the other constituents in poikilitic fashion. The augite is usually intersertal with reference to the feldspar and incloses all the accessories. The sequence of crystallization appears to have been (in order from the oldest to the youngest mineral) as follows:

Apatite.
Titanite, zircon and ilmenite.
Feldspar. ⎫
Augite (and hornblende). ⎬ Nearly contemporaneous.
Biotite. ⎭
Quartz.

The composition of the biotite, augite, and hornblende not being known, it is not possible to calculate the analysis. The analysis agrees with the microscopic examination in placing this rock decidedly in the class of true diorites, as a *biotite-augite-hornblende-diorite*. For ease of reference, columns 2 and 3 are entered in Table IV in order to show the similarity between our rock and a fair average diorite and also the limits of chemical variation which can be found in a list of typical analyses from that rock group. From its field associations one might expect the Basic stock to have given a higher proportion of alkalies in its average phase. For this reason column 4 has been added to point the dissimilarity between the Ascutney rock and essexite, the alkaline type nearest to it in general habit. The absence of monoclinic feldspar and of olivine among the constituents, and the relatively low proportion of soda and of ferric iron compared to the essexite, serve to dispel the a priori notion that the alkaline stocks on the east should be accompanied, in their common conduit, by an intrusive of essexitic or allied alkaline habit if that intrusive were to be a plagioclase rock of basic character.

Phase c.—A second phase intimately allied to the first, both in field relations and lithological characters, is represented in a long series of outcrops lying southeast of Mr. Pierson's house on the Notch road. Two specimens of the brownish-gray, medium-grained rock were selected at a point 500 yards distant from the house, and proved to be a normal *biotite-hornblende-diorite*, with structure and accessories similar to those in phase *d* (spec 32). The feldspars generally show two zones of growth; the cores average a labradorite between Ab_1 An_1 and Ab_2 An_3, the narrower mantling zone averaging the oligoclase Ab_3 An_1. The average soda-lime feldspar is probably close to that of the analyzed phase. The chief difference from the latter rock lies in the replacement of the augite by an idiomorphic brown hornblende of much deeper absorption than that characterizing the intergrown hornblende of phase *d*. Here the scheme of absorption is: **a**. Yellow. **b**. Deep brown, with a suggestion of olive-green. **c**. Deep chestnut-brown. $c > b > a$ or $c = b > a$.

One or two large subidiomorphic individuals of nearly colorless

augite have been found in the slides. In each case a broad mantle of the deep-brown hornblende surrounds the augite in parallel intergrowth. The biotite is of the same nature as in phase *d*, but much less abundant and seldom poikilitic.

TABLE IV.—*Analyses of diorites and essexite.*

	1.	2	3.	4.
SiO_2	52.12	56.52	52.00–62.80	47.94
Al_2O_3	16.35	16.31	12.41–18.00	17.44
Fe_2O_3	3.68	4.28	0.77– 7.42	6.84
FeO	6.02	5.92	2.41–12.84	6.51
MgO	4.14	4.32	2.02– 8.03	2.02
CaO	7.25	6.94	4.99– 8.98	7.47
Na_2O	3.65	3.43	2.31– 4.65	5.63
K_2O	2.34	1.44	0.44– 2.37	2.79
H_2O above 110° C	0.88	1.03	0.16– 2.24	2.04
H_2O below 110° C	0.25			
CO_2	0.07			
TiO_2	2.10	0.25	0.03– 1.10	0.20
ZrO_2	0.02			
P_2O_5	0.89	0.40	0.17– 1.06	1.04
Cl	0.09			
F	0.08			
FeS_2	0.24			
NiO, CoO	Trace.			
MnO	0.17	0.14		
BaO	0.04			
SrO	Trace?			
Li_2O	Trace.			
	100.33	100.98		99.92
O=F, Cl	0.03			
	100.30			
Total S	0.13			
Sp. gr	2.936			

1. Biotite-augite-hornblende-diorite, Basic stock, Ascutney Mountain. Analysis by Hillebrand.
2. Average of a series of 16 typical diorites, compiled by Brögger, Die Eruptivgesteine des Christianiagebietes, Vol. II, 1895, p. 37.
3. Limits of variation in the above-mentioned 16 analyses.
4. Classic essexite, Salem Neck, Salem, Mass. Analysis by Dittrich.

Phase b.—At various points in the stock, especially west and south of Pierson Peak and near the crest of Little Ascutney ridge (spec. 61),

the rock becomes coarser than in either of the two phases just described and shows a distinct difference of composition from either. At the same time, repeated examination of ledes in the field could discover no difference of age among the three. This third phase is dark colored and remarkable for its richness in bisilicates, which have a strong poikilitic habit. Augite and biotite of the general character of those minerals in phase *d*, and large independent crystals with augite intergrowths of brown hornblende similar to that in phase *c*, are the essential dark-colored constituents. The biotite has, however, an optical angle considerably greater than elsewhere observed in the stock; it was measured and found to be a few minutes more than 9°.

A long series of feldspar determinations accorded with one's first impression of the rock in studying the hand specimen, that it belongs to a phase much more basic than *c* and *d*. The prevalence and large size of the Carlsbad albite twins and the uniform behavior of the feldspar enables us to state conclusively that the average feldspar in this phase is close to basic labradorite, Ab_2An_3, with a narrow range above and below the acidity of that mixture. Primary quartz is entirely absent. Nearly colorless titanite is especially abundant, both alone and surrounding the large ilmenites after the manner of leucoxene.

The basicity of this phase unquestionably places it among the gabbros, and it may be called a *hornblende-biotite-augite-gabbro*, notwithstanding the absence of true diallage among the constituents.[a] It probably rivals phase *d* in the amount of surface covered in the stock.

Phase a.—In the fields west-southwest of Pierson Peak a fourth variant of the rock outcrops in the form of an unusually coarse-grained type (spec. 112). It is more feldspathic than phase *b* and hence of a lighter color. Biotite and hornblende have almost completely disappeared, the former being a rare accessory, the latter forming occasionally a mantle about augite. The light reddish-brown feldspar is again very uniform and averages the basic labradorite, Ab_2An_3. The usual accessories are present excepting quartz. The structure is the hypidiomorphic granular, but on account of the intersertal relation of the augite to the feldspar, it assumes the special habit of diabase. The poikilitic nature of the augite is very striking. The phase has the composition and other characters of a typical diabase excepting in its geological occurrence. It may be called an *augite-gabbro*, though diallage is here, too, wanting.

Phase e.—Finally, a fifth phase remains to be noted, which is not important on account of the amount of area covered by it in the stock as a whole, but which merits particular attention on account of its

[a] We can not but agree with Judd (Quart. Jour. Geol. Soc., Vol XLII, 1886) and Lacroix (Bull. serv. carte geol France, No. 67, Vol. X, 1899, p. 27) in regarding it as indifferent, for purposes of nomenclature, whether the pyroxene of a gabbro possess the diallagic structure or not.

forming a transitional rock type between the true gabbros and diorites on the one hand and the alkaline rocks of the region on the other. This phase was discovered just north of the contact between the stock and the great syenite-porphyry dike of Little Ascutney, and opposite the middle of that dike. The rock is fairly fresh and tolerably coarse grained, and is rich in feldspar, brown hornblende, and biotite (spec. 59). Augite forms in a few rare instances small cores of hornblende intergrowths. The accessories common to all the phases are present, and, in addition, some free interstitial quartz. But the feldspars are in great contrast to those so far noted as occurring in the stock. Plagioclase, averaging near the andesine Ab_5An_3 is dominant; oligoclase ranging between Ab_3An_1 and Ab_2An_1 is common. The plagioclase is sometimes surrounded by a mantle of oriented microperthite. What is still more noteworthy is the existence of much free orthoclase and microperthite alongside the triclinic feldspar. The order of crystallization is as follows:

Apatite.
Titanite, zircon, and ilmenite.
Augite, hornblende, and biotite.
Oligoclase-andesine.
Orthoclase and microperthite.
Quartz.

The structure of the rock is the usual hypidiomorphic granular. Its true relation to the diorites is indicated if we call it an *orthoclase-microperthite-bearing hornblende-biotite-diorite*. Yet the rock is clearly allied to a somewhat acid form of essexite.

BASIC SEGREGATIONS.

In phase *e*, at the locality indicated, basic segregations were sparingly found (spec. 59a). These are of distinctly darker color than the parent rock, and both macroscopically and microscopically are seen to be finer grained. They are roundish in form and average about 1 inch (2.6 mm.) in diameter. The boundary between nodule and parent rock is not definite; they merge into each other in a gradual way. The nodules are essentially composed of plagioclase, hornblende, and biotite grouped with a panallotriomorphic structure. The feldspar is zoned; the most acid zone is the oligoclase, Ab_4An_1, and the average feldspar is near labradorite, Ab_1An_1. No certain orthoclase or microperthitic feldspar could be identified in the slide. The dark constituents have the usual properties of those minerals in this stock. The augite is more abundant here than in the parent rock, though again generally it occurs in the form of intergrowths with the hornblende. Zircon is very rare, but apatite unusually abundant. A little interstitial quartz is accessory.

TABLE V.—*Analysis (by Hillebrand) of hornblende-biotite-diorite nodule.*

	Per cent.
SiO_2	55.28
Al_2O_3	17.23
Fe_2O_3	1.54
FeO	6.23
MgO	2.69
CaO	5.60
Na_2O	5.42
K_2O	2.12
H_2O above 110° C	0.71
H_2O below 110° C	0.20
CO_2	0.04
TiO_2	1.64
ZrO_2	Trace.
P_2O_5	0.73
Cl	0.07
F	0.28
FeS_2	0.07
MnO	0.24
BaO	0.06
SrO	Faint trace.
Li_2O	Trace.
	100.15
O=F, Cl	0.13
	100.02
Total S	0.038
Sp. gr	2.822

The analysis of one of these nodules agrees with the microscopic diagnosis (except in the matter of structure) in placing it in classification among the hornblende-biotite-diorites (Table V). The high soda relates the nodule to essexite. It is more basic than its host, though more acid than the diorite analyzed (phase *d*.) The high fluorine is again noteworthy.

DIORITIC DIKES CUTTING THE BASIC STOCK.

Following the consolidation of the Basic stock the same magma which it represents seems to have been erupted a second time, and as a result we have networks of interlacing dikes in various parts of the stock. These are oftentimes so numerous as to give the bare ledges the appearance of mosaics on a large scale. Occasionally the younger intrusive has so extensively displaced the older as to form miniature stock-like bodies sending out apophyses into the coarser rock and inclosing horses of the latter. The mosaics are thus intrusion-breccias or flow-breccias. The younger intrusives cut with apparent indifference both the gabbroitic and the dioritic phases of the stock.

In color, mineralogical and chemical composition, and even in

structure, the dikes are closely allied to the diorite analyzed. In the fields southeast of Pierson Peak both the younger and older rocks are augite-biotite-hornblende-diorites (spec. 147). Within a hundred yards a second network of dikes is characterized by the complete absence of hornblende and by a remarkably perfect zonal structure in its feldspar (spec. 145*a*). The great range in acidity of these feldspars was not found equaled in any other rock of the whole region. By the method of equal illumination, checked by the behavior of each zone in convergent light, it could be proved that the core of such a feldspar may be a true anorthite. Outside the core basic labradorite near Ab_1An_2 is succeeded by a third zone of oligoclase near Ab_2An_1, and outside of all there comes a narrow zone of the albite $Ab_{12}An_1$. The average of several determinations on Carlsbad albite twins gave basic oligoclase, Ab_2An_1, as the average feldspar of the rock. The usual accessories are present. This rock is a typical *augite-biotite-diorite.*

A very similar type occurs in the form of a series of parallel dikes on the northern slope of Little Ascutney and at its eastern end (spec. 184). Here a significant amount of orthoclase was discovered among the accessories. In immediate association with the first group of reticulate dikes mentioned, another group of a lighter color but of similar structure showed in the microscopic examination a still greater proportion of orthoclase, which is accompanied by microperthite. The bulk of the feldspar is still, however, near the basic oligoclase Ab_2An_1. Biotite is the only other essential. Augite fails and brown hornblende is a rare accessory. The type may be called a *biotite-diorite* bearing accessory orthoclase and microperthite.

"WINDSORITE" DIKES CUTTING THE BASIC STOCK.

Potash-feldspar finally becomes of nearly equal importance among the essential minerals of these rocks in a set of light-colored, pinkish-gray dikes 1 to 3 feet (0.3 m. to 0.9 m.) in width; traversing the stock in the notch just northeast of the eastern end of Little Ascutney (spec. 77), and again on the notch road near Mr. Pierson's house. The dikes at the former locality seem to have been cut off by the porphyry occurring on Little Ascutney. The plagioclase varies from andesine, Ab_5An_3, to oligoclase, Ab_3An_1, the average mixture being probably basic oligoclase, Ab_2An_1. The triclinic feldspar is often surrounded by mantles of orthoclase or microperthite. Orthoclase, microperthite, and, probably, soda orthoclase, especially the first two named, are the alkaline feldspars, the abundance of which is reflected in the chemical analysis of this rock type (Table VI, column 1).[a] Shreds, irregular plates, and, rarely, idiomorphic crystals of biotite represent the only other essential. Rare grains of augite and still rarer bleached indi-

[a] Through a mistake, a fragment of diorite from the younger dikes was included in the sample of this rock sent to Washington for analysis. This unfortunate fact explains the difference between column K (the vitiated analysis) and column L on page 69 of Bulletin 148 and on page 25 of Bulletin 168 of this Survey.

viduals of hornblende with ilmenite, apatite, zircon, and (doubtfully) titanite, compose the list of accessories. Pyrite developed secondarily on the joint planes explains the sulphide of the analysis. The mica must be rich in magnesia and is probably a meroxene. Quartz occurs interstitially in comparatively large amount. The bisilicate and biotite exhibit a great amount of magmatic resorption, and it is therefore difficult to be certain of the order of crystallization. It is probably as follows:

Apatite.
Zircon.
Ilmenite and titanite.
Biotite, augite, and hornblende.
Andesine and oligoclase.
Microperthite, orthoclase, and soda orthoclase.
Quartz.

No analysis of the mica has been made. On account of its small amount in the rock, no serious error in the calculation of the other and more important essentials will be made if we assume that in the biotite there is 20 per cent MgO, 40 per cent SiO_2, and 8 per cent K_2O. On this supposition, the quantitative mineralogical composition of the rock was calculated as follows:

Mineralogical composition of windsorite.

	Per cent.
Albite molecule	38.5
Orthoclase molecule	28.5
Anorthite molecule	11.5
Quartz	13.0
Biotite	5.0
Magnetite and ilmenite	2.5
Diopside, apatite, and zircon	1.0

If the average plagioclase = Ab_2An_1, the rock contains 34.5 per cent soda-lime feldspar and 44 per cent alkali feldspar.

TABLE VI.—*Analyses of windsorite and other rocks.*

	1.	2.	3.	4.	5.
SiO_2	64.62	67.14	65.00	59.00–68.50	65.65
Al_2O_3	16.46	15.37	16.00	14.00–17.00	16.84
Fe_2O_3	1.82	2.24	1.50	1.50– 2.25	4 01
FeO	2.14	1.93	3.00	1.50– 4.50	
MgO	1.10	1.36	2.00	1.00– 2.50	0.13
CaO	2.39	3.60	5.00	3.00– 6,50	2.47
Na_2O	4.57	3.29	3.50	2.50– 4.50	5.04
K_2O	5.21	4.06	2.25	1.00– 3.50	5.27
H_2O above 110° C	0.39	0.59			0.30
H_2O below 110° C	0.13	0.07			
CO_2	0.11				
TiO_2	0.81				
ZrO_2	0.03				
P_2O_5	0.21				
Cl	0.05				
FeS_2	0.19				
MnO	0.12				
BaO	0.03				
SrO	Trace.				
Li_2O	Trace.				
CuO	Trace.				
Remainder		0.35	1.75		
	100.38	100.00	100.00		99.71
O=F, Cl	0.01				
	100.37				
Total S	0.10				
Sp. gr	2.666				

1. Dike of windsorite, Little Ascutney Mountain; analysis by Hillebrand.
2. Average of two typical quartz-monzonites, from the Sierra Nevada. Turner, Jour. Geol., Vol. VII, 1899, p. 152.
3. Average composition of granodiorite, according to Lindgren. Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1896, p. 35.
4. Limits of variation in granodiorite, according to Lindgren. Ibid., p. 35.
5. Alkaline augite-hornblende-syenite (nordmarkite), Diana, New York; analyzed by C. H. Smyth, Bull. Geol. Soc. Am., Vol. VI, 1895, p. 274.

Table VI represents type analyses of related rocks. Of these and of the Ascutney dike the essential mineralogical composition is as follows:

1. Basic oligoclase, microperthite, orthoclase, quartz, biotite.
2. Oligoclase, quartz, orthoclase, biotite, amphibole.

3. Oligoclase-andesine (usually andesine), quartz, orthoclase, biotite, green hornblende.
5. Microperthite, albite, augite, hornblende.

This rock belongs to another type intermediate between the orthoclase rocks and the plagioclase rocks. It is almost identical in chemical composition with certain nordmarkites (cf. col. 5), but the lime is practically all in the highly important essential, basic oligoclase. This character definitively removes the rock from the nordmarkites. We can not, on account of the high alkalies and relatively low lime, place it in the group of the granodiorites (cf. cols. 3 and 4), nor, for the same reason, in the group of the quartz-monzonites (cf. col. 2), though in general the affinities are stronger with the last-named group than with any other already well-defined type. The soda and the combined alkalies are too high to characterize a normal lime-alkali quartz-syenite. The rock is, in reality, a leukocratic analogue of the quartz-monzonites in which augite is replaced by biotite. It may also be considered as the alkaline equivalent of granodiorite. Standing in a class by itself, both with respect to the other Ascutney intrusives and with respect to the types now recognized in our rock classifications, the name *windsorite* is proposed for the rock in order to fix this type and to facilitate reference to it. The name is taken from that of the neighboring town northeast of the main mountain. Windsorite may be defined as a leukocratic, hypidiomorphic-granular rock, composed essentially of alkaline feldspar (microperthite and orthoclase), basic oligoclase, quartz, and biotite, and characterized by high alkalies (potash slightly in excess of the soda), relatively low lime (contained essentially in the plagioclase), low iron, and low magnesia.

SYENITES.

The Basic stock is cut by several large independent bodies of syenitic habit. Their rocks are so similar in compositon that, as in the case of the dioritic rocks, a detailed petrographical description of a chief phase in one of the bodies will suffice to illustrate the larger part of what may be said in description of the other phases and related intrusives. In this way some repetition may be avoided.

MAIN SYENITE STOCK; ITS PHASES.

As we have already seen, Mount Ascutney owes its strong relief to the largest intrusive mass in the area discussed—the Main syenite stock covering about 4 square miles (10.5 square kilometers). The intrusive character of the rock is plainly indicated at almost any part of the contacts with the diorites, gneisses, or phyllites (see Pl. VI). The walls of the conduit appear to be usually nearly vertical, inasmuch as the line of contact in all but two or three cases runs straight across the radiating gulches and does not turn up or down the corresponding brook

beds. The latter rule is departed from at three of the largest ravines in the mountain. At Crystal Cascade the schists stand vertical or dip at high angles to the east-northeast. They form a blunt projection into the igneous body, and, on account of their relative softness, the strong gulch below the cascade has been worn out. The actual surface of contact between schist and syenite is exposed for a vertical distance of 100 feet. That sample contact is nearly vertical. A second deep ravine, 1 mile east of the cascade, may be explained as located on a similar broad tongue of schist less resistant to the weather than the syenite to right and left of the ravine. At only one point does the surface of contact seem to depart from verticality, namely, at the picturesque ravine south of Brownsville. There the schists dip under the syenite as if the latter had, during intrusion, followed the planes of schistosity after the manner of a sill or laccolith. But this observation stands alone, and such a structural relation must be regarded as exceptional and very local.

The syenite showed a general independence of the structure of the invaded rocks as it found its way up from its deep-lying source. Both to north and to south of the mountain the schists strike steadily toward the stock. They are not essentially displaced from their original tilted position, except as a result of some relatively slight crumpling in the contact zone, but are cut squarely off by the syenite. This is true at the eastern contact as well. At several points the contact plane was observed to cut across the structural plane of the phyllites. If, however, the intrusion had been controlled by the latter, we should expect the surface of contact to dip eastward and the zone of metamorphic change in the schists to be broader there, at the eastern end, than elsewhere. The facts do not agree with either conclusion.

The syenite thus constitutes a pipe-like stock of roundish outline, the cylindrical form being modified by a few large projections of schist in place and by the irregular stock of the younger Ascutneyville granite.

A notable characteristic of the Main stock, as of the older one, is the variability of the rocks composing it. Though they are everywhere related to the group of the alkaline syenites, they exhibit important mineralogical, chemical, and structural differences. Four chief types of the variations in color, grain, structure, proportion of dark-colored to light-colored constituents, and the distribution of inclosed basic segregations, are to be distinguished. In the field the transition of these types into one another is so complete that they must be regarded as the differentiated product of one body of magma. As yet there is no certain observation forthcoming to show that there was more than one eruptive period for all four, even in the sense of the intimately associated diorite and reticulate dikes of the Basic stock, or in the sense of Brögger's hypothesis of the cutting of still unconsolidated augite-syenites by elæolite-syenite. It will be remem-

bered that Brögger introduced that hypothesis in order to explain the field association of the Christiania rocks.[a]

Like the still younger granite, the syenite has, in general, a finer texture than the gabbro-diorites. This contrast is to be related to the greater basicity of the latter rather than to any essential difference of physical conditions under which the intrusion of the basic and acid stocks occurred.

Phase f, nordmarkite of granitic habit.—The only quarry that has recently been worked in the Ascutney area is situated within a few hundred feet of the contact with the schists in the first of the four phases of the Main syenite. Various attempts have been made to use the stone for monuments and for ornamental purposes generally, but, for a reason which will be noted further on, a market could not be permanently secured by the owners. The quarry seems to have been practically abandoned. The finest blocks yet taken out are doubtless those which are to be seen in the large columns of the library building at Columbia University, New York City.

The rock, as represented in the quarry, is a handsome, dark-green syenite, in this place characterized by medium to coarse grain and a typical eugranitic structure (spec. 42); elsewhere this phase grades into one possessing a trachytic structure. It is a syenite with variable amounts of free quartz and a low percentage of colored constituents. Primary veins or flow streaks are common; they are usually finer-grained than the average rock, and are even more poorly provided with bisilicates. In addition to the feldspars and accessory quartz, the list of minerals includes, in the order of their abundance, a hornblende, biotite, a pyroxene, allanite, titaniferous magnetite, apatite, pyrite, zircon, monazite, and a lime-iron garnet. The order of their crystallization seems to have been as follows:

Apatite.
Zircon.
Magnetite, pyrite, garnet.
Monazite and allanite.
Augite, hornblende, and biotite.
Oligoclase.
Alkaline feldspars.
Quartz.

The feldspars.—The constituents which determine the structure, texture, and color of the syenite are the feldspars (Pl. IV, *A*.) Of these, microperthite is by far the most abundant, and with it are associated orthoclase, soda-orthoclase, microcline, and a plagioclase. There is no observable difference in the macroscopic habit of these feldspars, and it was only by the careful study of slides and rock powder that all the species could be determined. All of them are undoubtedly the product of primary crystallization.

[a] Zeit. für Kryst., Vol. XVI, 1890, p. 281.

The microperthite is especially interesting on account of its typical development. The usual intergrowth is that of orthoclase with a plagioclase varying from albite to an acid oligoclase near Ab_5An_1, but on many cleavage pieces it was easily proved that the triclinic feldspar was intergrown with a monoclinic, itself strongly charged with the soda molecule. Such individuals gave extinctions of 12° and 19° on (010) for the two kinds of lamellæ, thus indicating the association of nearly pure albite with an orthoclase that stands at the extreme soda end of the series, generally designated by the name "soda-orthoclase." In all cases the intergrowth follows the law whereby the triclinic lamellæ lie in the monoclinic feldspar parallel to a steep orthodome; the angle of 72° between the albite lamellæ and the basal cleavage on (010) indicates that this dome may be ($\bar{8}01$), the one noted in this relation to intergrowth by Brögger. From the normal microperthite there are all transitions to what would appear to be true cryptoperthite. Both ends of the series sometimes show the murchisonite parting, which is unusually clean and definite.

The tabular crystals of well-lamellated microperthite from a highly feldspathic phase on the Brownsville slope of the mountain represent a very high proportion of soda in the mixture, as shown by the polarization phenomena and the specific gravity of from 2.610 to 2.611 at 17° C. Generally, however, the proportion of potash to soda is about 1:1, corresponding to a specific gravity of from 2.584 to 2.595 at the same temperature. The same average ratio is believed to characterize the feldspars of the rock as a whole. It is true that there is a not unimportant amount of orthoclase and soda-orthoclase in most of the slides, yet this lowering of the otherwise high percentage of soda is occasionally counterbalanced by a little free oligoclase and always by a microperthite which is richer in the triclinic component than the average stated.

The pure potash feldspar is relatively rare. It occurs as orthoclase and as microcline, both contemporaneous with the microperthite in their period of crystallization.

The plagioclase is no more than accessory. The usual optical methods of determination agreed in showing that it belongs to a series from practically pure albite to the oligoclase Ab_5An_1. Anorthoclase could not be demonstrated in any of the Ascutney rocks, nor should it, on account of the lowness of lime, be expected. Barium oxide doubtless occurs in isomorphic relation with the soda and potash of the feldspars. No hyalophane has been discovered in the rock.

Rapid tarnishing on exposure to air.—One of the most remarkable properties of this rock consists of the unstable character of its color. When broken out of the quarry a fresh specimen is uniformly, on the surface of fracture, a light bluish gray. In the course of twenty-four hours, under atmospheric conditions, this tint changes to one with a greenish tinge, and after an exposure to the air of about thirty days

it has become a deep brownish green—the color we have noted for the numerous blocks of the quarry. This green color is in its turn lost when the rock has suffered more pronounced weathering after many years of exposure. The final change gives the familiar yellows and browns of a decomposed ferruginous rock. In this stock the rapid change from gray to green was observed only in phase *f*, as exposed on the north and northwest slopes of the mountain.

Examination quickly showed that the color change of the rock is conditioned by the feldspar and that it is altogether a superficial phenomenon, taking place only where the air has access to the mineral. The question has naturally arisen as to the cause of this peculiar instability of color, and a number of experiments were carried out which have thrown light on the problem. To show that one or more of the principal atmospheric gases were essential to the reaction, a gray piece of the fresh rock was immersed in a stream of carbon dioxide gas for twenty minutes and then kept in an atmosphere of that gas for twenty-four hours. No appreciable change was noted in the original gray tint, showing that in all probability the carbonatization of some unknown element in the feldspar could not explain the alteration of tint. The inference was ready to hand that it was rather due to oxidation. A gray fragment of the rock was accordingly placed in an atmosphere of purified oxygen over night. A perceptible change to the green color resulted. The same piece was then changed to an intense green by an exposure of thirty minutes to a stream of oxygen, while the fragment was kept at a temperature of about 150° C.

The further question remained: What oxidizable substance present in the feldspar would, on uniting with the oxygen of the air, furnish the required color? That it is not organic was shown by the fact that before the blowpipe the green tint was not only not destroyed, but, on the contrary, was deepened in the oxidizing flame—another testimony to the fact of oxidation as the true cause. Partial decolorization resulted from the application of the reducing flame. The probable explanation of the color change is found in the oxidation of the ferrous oxide of the feldspars to the ferric, thus giving a yellow which, in combination with the fundamental blue-gray of the under layers of the crystal substance, affords the green of the altered surface. In acids the mineral is decolorized to the original bluish gray, which is permanent, and the filtrate gives a strong reaction for iron. A high power of the microscope shows that the perfectly fresh feldspars are all crowded with myriads of extremely minute blackish granules. It is possible that this dust is composed of ferrous oxide, dating as to its period of formation from the time of the original crystallization of the rock. If this be true, we can derive the instability of color from one of the most familiar reactions in the history of metasomatic processes.

Were the coloring substance uniformly distributed throughout the

body of the rock, this syenite would make a favorite material for decorative purposes, for it is capable of a fine polish; but the distribution is, unfortunately, very uneven, and the consequence is that the polished monument or shaft is often blemished with streaks of lighter and darker hue than the average. Furthermore, as already implied, the tint of any specimen can never be said to be permanent. As the oxidation progresses, the bluish tone of the feldspar substance beneath the surface will have less and less influence on the color mixture and a more brownish tone will result. This is what has actually happened in the case of several tombstones which have stood for some years in the cemeteries of Brownsville and Windsor.

A similarly rapid change of color—from a grayish green to a more pronounced green—on exposure to the air, has been described by Cushing as characterizing the squeezed augite-syenites near Loon Lake, New York.[a] He suggests staining from the oxidation of the ferrous iron derived from decomposed hypersthene as a possible cause of the rusty brown color, but leaves open the question of the causes of the early stages of the color change. He points out that the uncrushed crystals are always less green than the feldspar granulated by pressure. This would be expected as one result of the increased ease with which oxidizing fluids would circulate in the rock after crushing. The gray color of the Ascutney rock corresponds with its other properties in showing that it has not been subjected to such squeezing as that once suffered by the New York syenite, which in other respects is strikingly similar to our rock. Types very close to both of these in nature and origin occur at Killington Peak in western Vermont and at Shefford Mountain, Quebec, and possess the same peculiar green color. At the latter locality the change from the fresh gray to green has also been observed. It may be noted in passing that green is a favorite hue for several species of alkaline rocks. Tinguaites are commonly green, like the groundmass of pantellerites, and grorudite from the classic locality is green, the color in the last mentioned rock being due, however, to the essential ægirine.

Hornblende.—The next most important constituent of the syenite is a hornblende belonging to the alkali-iron group of amphiboles. Often idiomorphic against the feldspars, it yet commonly possesses the feature characteristic of hornblendes that have grown in an alkaline magma—namely the irregular outline due to resorption.[b] Within the cavities thus formed by this magmatic solution, feldspar and quartz have crystallized, and in section have the appearance of inclusions in the hornblende. The color of the mineral varies through shades of brown according to the following scheme:

a, light greenish brown to grayish yellow.
b, deep greenish brown to olive-brown.
c, grayish olive-green.

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[a] Bull. Geol. Soc. Am., Vol. X, 1899, p. 178.
[b] Cf. Brögger, Zeitschr. für Kryst., Vol. XVI, p. 131.

The absorption parallel to **b** and **c** is very strong; **b**>**c**>**a**.

By the use of cleavage pieces mounted on the Fedoroff table, the extinction was determined on (010) at 16°. The extinction on the cleavage plate itself was found to average 14° 39′. By turning the plate about an axis at once coincident with the vertical axis of the crystal and parallel with the principal section of the polarizer, it was possible to test the curve of extinction in the vertical zone. Readings were taken at positions of the cleavage plate where the plane of symmetry made angles of 42° 30′, 47° 30′, and 77° 30′ with the plane passing through the crystal at right angles to the axis of the microscope. The corresponding angles of extinction were found to be 16° 50′, 17° 25′, and 12° 0′. These results mean an angle of extinction on (010) of 16°, and an optical angle of about 70° for the amphibole.[a] Etch figures on a cleavage plate immediately oriented the crystal and therewith the ellipsoid of optical elasticity.[b] The optical axis **c** lies in the obtuse angle β in Tschermak's orientation. These conclusions were checked by the close study of rock slides, and chance sections of the hornblende favorable to the rough measurement of the optical angle and to the determination of c : **c** confirmed the results derived from the use of cleavage pieces.

The usual twinning parallel to (100) was observed.

The angle of the cleavage prism was measured on about twenty individuals and found to vary from 55° 13′ to 56° 0′, with an average of 55° 32′. This great variation from the mean is not to be explained by poor reflexes or by the personal equation of the observer, but must be conditioned by some as yet unknown cause or causes.[c] The specific gravity was taken with the Klein solution; it averaged 3.272 at 17°C., varying in a suite of ten specimens from 3.266 to 3.278. A thin splinter of the mineral melts quietly in the Bunsen burner with a strong soda flame. In view of such properties we can place this hornblende near barkevikite, in the alkali-iron series developed by Brögger.[d] Poikilitic intergrowths with biotite and allanite and parallel intergrowth with augite make it impossible to separate the hornblende and thus permit a chemical analysis of it being made, but it is plainly rich in ferric oxide and soda.

Augite.—Compared with the amphibole, the pyroxene is present in very subordinate amount. It almost invariably occurs in the cores of parallel intergrowths with the hornblende, which there is every reason to believe is primary and has thus not been derived from the pyroxene either by magmatic or by metasomatic changes. The augite has the usual diopsidic habit of most augite-syenites; the optical angle

[a] Proc. Am. Acad. Arts and Sciences, Vol. XXXIV, 1899, p. 311.

[b] Ibid., p. 373.

[c] There is need for a thorough investigation of the whole amphibole group for the purpose of fixing the series of prismatic angles, as they undoubtedly vary with the chemical composition, and the student of the amphiboles would probably be repaid if he set about the task of finding the possible causes for the noteworthy variation in the angle for the same species from one locality.

[d] Gesteine der Grorudit-Tinguait Serie, p. 33.

is, however, remarkably small, 45° 15′ being measured in oil. The extinction angle was not found on account of the lack of favorable material.

Biotite.—In about equal proportion with the pyroxene is a deep-brown primary mica characterized by normal properties. The optical plane and the plane of symmetry are coincident. From the low percentage of magnesia in the total analysis it appears that the mica is a true lepidomelane and not a meroxene. The formation of skeleton crystals by magmatic resorption is here also very striking.

Allanite.—The rock of the Windsor quarry contains an important accessory not recognized in any other part of the syenite stock. It occurs in the form of elongated anhedral grains, either independent or associated as irregular intergrowths with the hornblende. In the hand specimen the mineral can be readily made out by its black color, waxy to lustrous appearance, and by the presence of only one good cleavage. In many cases the individuals are as much as half a centimeter long. The most striking microscopic property is the extremely strong pleochroism and absorption. The colors vary from cinnamon-brown to deep walnut-brown in some individuals; in others chestnut-brown and purplish brown appeared, while in the thicker slides the more powerful absorption gave almost absolute blackness. The single refraction seemed to be higher than that of hornblende, but the double refraction was weaker. In addition to the good cleavage visible macroscopically, there was also present a less perfect cleavage transverse to the former at a high angle. Before the blowpipe the cleavage pieces fused with intumescence to a black magnetic glass. Such an association of properties seemed to indicate allanite, and an examination of some material from Suhl (orthite) confirmed the close similarity with that mineral. The conviction became a practical certainty when some fragments were dissolved in hydrofluoric acid, and from the solution an excellent test for cerium was obtained by precipitating with ammonium oxalate.

The allanite is (on account of the strong magmatic resorption) never idiomorphic. Yet it must be one of the oldest constituents of the rock, as it is inclosed by the hornblende, in which it often forms lively pleochroic halos. The two minerals are sometimes intergrown, but the allanite never incloses the other. Apatite, zircon, and magnetite antedate both in the order of crystallization.

We have here, then, one more example showing the importance of allanite in eruptive rocks. As early as 1885 Iddings and Cross noted the occurrence of the mineral at 28 localities and in 9 rock-types, including granite, gneiss, granite-porphyry, quartz-porphyry, diorite, dacite, and rhyolite.[a] Since then it has been discovered at many other localities, including some where the rock is alkaline and related in character to the Ascutney syenite, e. g., the hornblende granite of

[a] Am. Jour. Sci., 3d series, Vol. XXX, 1885, p. 108.

Essex County, Mass.,[a] and the quartz-syenite of Loon Lake, New York.[b]

Monazite.—A second accessory which was attended with considerable difficulty in its determination occurs in some amount in the quarry rock. It has never been observed macroscopically, but only in the slide, where it is found in the form of roundish grains reaching 1 millimeter in diameter. These are nearly colorless, with a grayish-yellow tint, and are characterized by high single refraction and by high double refraction, giving polarization colors of the third order. Crystal form is always lacking, but optical tests showed the mineral to be biaxial and monoclinic or triclinic. The cleavages, about at right angles to each other, were seen in the section of one small individual. The mineral was found to be difficultly soluble in nitric acid and more easily in hydrochloric acid. From the solution a precipitate with molybdate of ammonia was obtained, one too abundant to be explained by the associated apatite, and thus showed the grains to belong, without doubt, to a phosphate. The quantity of the solution was so small as to render impossible the sure determination of the rare earths which should be expected if the mineral be really monazite. Yet it may best be ascribed to that species as the phosphate nearest in optical properties to the one with which we are dealing.

The grains inclose numerous apatite needles of great minuteness and a few square sections of magnetite. All three minerals seem to have crystallized before the essential constituents. The monazite further shows an interesting paragenesis with the allanite, the latter sometimes appearing as a mantle about the former. Such an intimate association of a phosphate with a member of the epidote family is rather surprising, but from the study of the material in hand both minerals seem to be primary.

The magnetite is titaniferous. It is inclosed as a primary mineral by all the other constituents except apatite. Its habit is the usual one of granitic eruptives.

Titanite is rather less common than in the diorites, but possesses the same features as in the older rock. It incloses apatite; its relation to zircon is indeterminable as to the period of crystallization.

Apatite is, as usual, most abundant in the vicinity of the bisilicates, and is accordingly here, as in the feldspathic phases of the stock as a whole, very rare.

Zircon is more common than in the phases of the Basic stock. Its habit is, however, the same, excepting that it here shows a pronounced color and pleochroism.

E, pigment irregularly distributed—pale violet and colorless.

O, solid color—paler violet.

The zircon is younger than the apatite and seems to have accompanied the titaniferous magetite in its crystallization. Irregular

[a] Jour. Geol., Vol. VI, 1898, p. 792.
[b] H. P. Cushing, Bull. Geol. Soc. Am., Vol. X, 1899, p. 180.

roundish inclusions with wide margins of total reflection are ascribed to imprisoned gas.

Quartz is uniformly allotriomorphic and interstitial. Fluid cavities and negative crystals are very numerous. The filling material of the latter could be well studied here on account of the remarkable perfection of the forms. In many cases double bubbles, that unite on heating the preparation, indicate carbonic acid gas in a saturated solution of water. The usual orientation of the negative crystals with their chief axes parallel to that of their host is easily demonstrable, especially in the isotropic sections of the quartz; in them the fluids lie in six-sided cavities, whose sharp outlines are of exceptionally clear definition.

The extremely few grains of reddish common garnet were found in this phase only in those thin sections made from specimens collected near the schist contact and are doubtless to be referred to slight endomorphic influence exercised by the country rock on the eruptive.

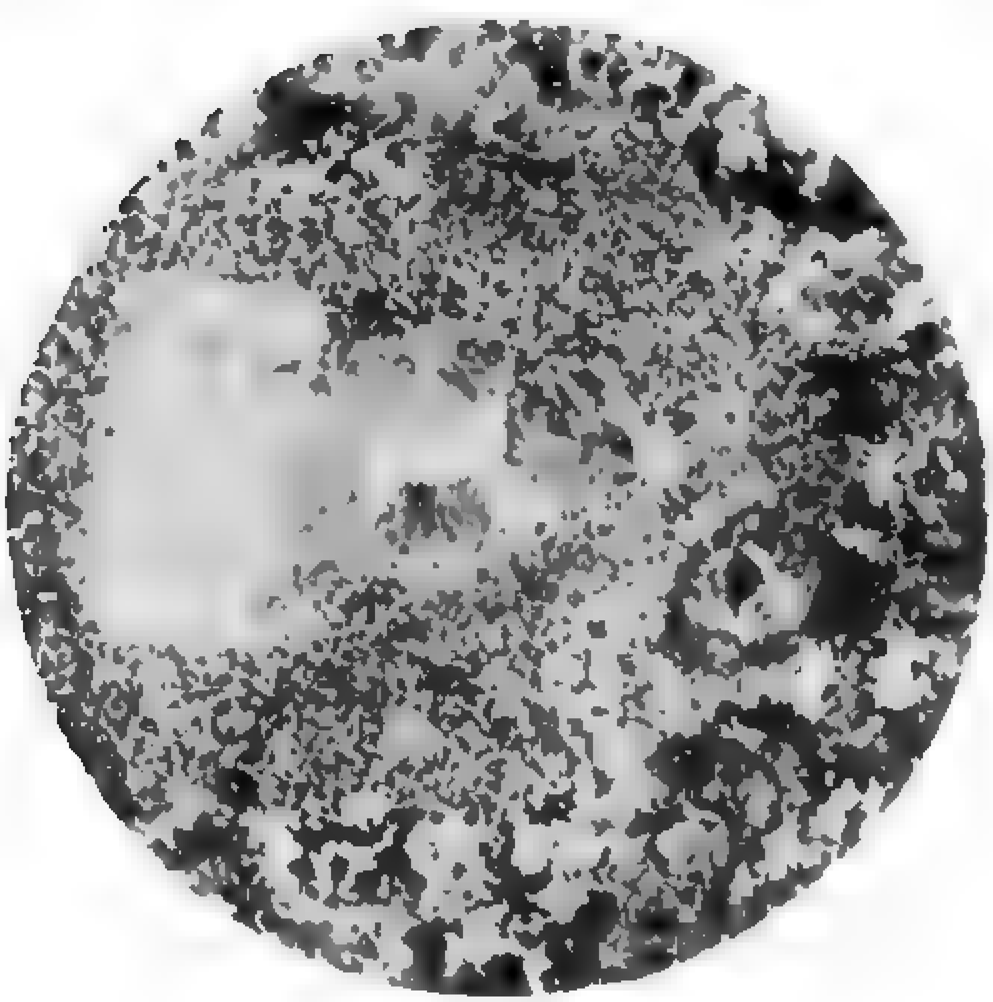
Basic nodules, from 1 to 2 inches (2.6 to 5.2 centimeters) in diameter are occasionally seen in the quarry rock. They are differentiated mineralogically from their parent rock simply by a greater richness in hornblende, which is here, too, strikingly corroded. One can not be sure that the poikilitic habit of the mineral is anything more than apparent; primary inclusion of quartz and feldspar might give the same appearance in thin section as that due to extensive embaying of the hornblende by the caustic feldspathic magma.

PLATE IV.

A. Typical thin section of the nordmarkite of the Main stock, granitic phase, composed almost entirely of microperthite and quartz; crossed nicols. $\times$ 20. (See p. 50.)

B. Pyroclastic feldspar (soda-orthoclase) surrounded by a reaction rim rich in alkaline hornblende, from the large paisanite dike on northwest slope of Ascutney Mountain; crossed nicols. $\times$ 7. (See p. 71.)

(A)



(B)

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TABLE VII.—*Analyses of nordmarkite and other rocks.*

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	65.43	64.88	64.04	60.45	60.03	60.5–67.0	61.49	65.43
Al_2O_3	16.11	16.24	17.92	20.14	20.76	20.0–17.5	16.14	16.96
Fe_2O_3	1.15	1.37	0.96	3.80	4.01	4.0– 3.0	5.81	1.55
FeO	2.85	2.70	2.08		0.75			1.53
MgO	0.40	0.89	0.59	1.27	0.80	1.0– 0.5	0.99	0.22
CaO	1.49	1.92	1.00	1.68	2.62	2.0– 1.5	1.67	1.36
Na_2O	5.00	5.00	6.67	7.23	5.96	7.0– 6.5	6.19	5.95
K_2O	5.97	5.61	6.08	5.12	5.48	5.0– 6.0	5.70	5.36
H_2O above 110° C	0.39	0.46	1.18	0.71	[a] 0.59	......	[a] 1.17	0.82
H_2O below 110° C	0.19	0.19						
CO_2	Trace?	None.	......	......	......	......	......	None.
TiO_2	0.50	0.69	0.62	......	......	......	......	0.16
ZrO_2	0.11	0.13						
P_2O_5	0.13	0.13	......	......	0.07	......	0.53	0.02
SO_3	None.	None.	......	......	......	......	......	0.06
Cl	0.05	0.04	......	......	......	......	......	0.04
F	0.08	0.08	......	......	......	......	......	......
FeS_2	0.07	......	......	......	......	......	......	......
BaO	0.03	0.06	......	......	......	......	......	None.
MnO	0.23	0.14	0.23	......	Trace.	......	0.28	0.40
SrO	Trace.	Faint trace.	......	......	......	......	......	......
Li_2O	Strong trace.	Trace.	......	......	......	......	......	......
	100.18	100.53	101.37	100.40	100.07	......	99.97	99.86
O=F, Cl	0.04	0.04	......	......	......	......	......	......
	100.14	100.49	......	......	......	......	......	......
Total S	0.036	......	......	......	......	......	......	......
Sp. gr	2.659	2.683	......	......	......	......	......	......

[a] Loss on ignition.

1. Hornblende-biotite-nordmarkite of granitic structure, Ascutney Mountain (phase *f*); analysis by Hillebrand.
2. Hornblende-biotite-augite-nordmarkite of porphyritic structure, Ascutney Mountain (phase *g*); analysis by Hillebrand.
3. Classic nordmarkite, Tonsenås, Norway; Brögger, Zeitschr. für Kryst., Vol. XVI, 1890, p. 54.
4. Classic nordmarkite, Aueröd, Norway; Brögger, ibid., p. 54.
5. Classic pulaskite, Fourche Mountain; Williams, Arkansas Geol. Surv., Ann. Rept. for 1890, Vol. II, p. 70.
6. Limits of variation in nordmarkites and related quartz-syenites, according to Brögger, op. cit., p. 81.
7. Average analysis of three syenite-porphyry dikes from the northern Adirondacks; Cushing, Bull. Geol. Soc. Am., Vol. IX, 1898, p. 248.
8. Nordmarkite of Shefford Mountain; Dresser, Am. Geol., Vol. XXVIII, 1901, p. 209.

From the analysis of the fresh quarry rock (Table VII, col. 1) the table of molecular proportions was calculated as follows:

	Analysis.	Molecular proportions.
SiO_2	65.43	1.0905
Al_2O_3	16.11	0.1579
Fe_2O_3	1.15	0.0079
FeO	2.85	0.0396
MnO	0.23	0.0032
MgO	0.40	0.0100
CaO	1.49	0.0266
Na_2O	5.00	0.0806
K_2O	5.97	0.0635
TiO_2	0.50	0.0061
ZrO_2	0.11	0.0011
P_2O_5	0.13	0.0009
Cl	0.05	0.0014

A partial determination shows that zircon forms 0.2 per cent of the rock; apatite, 0.4 per cent; magnetite (crediting it with all the Fe_2O_3), 1.8 per cent. A careful mechanical separation of the hornblende permitted a rough estimation of its total amount; slightly impure from included and intermixed allanite, biotite, and magnetite, it composed 5.2 per cent by weight of the total powder. Allowing for its impurity, we shall not be far from the truth in regarding 5 per cent as the proportion of hornblende. Arbitrarily estimating the lime content of the hornblende as 10 per cent (near barkevikite), the proportion of the anorthite molecule, after allowing also for the lime in the apatite, was calculated at 4 per cent. On the supposition that all the soda occurs in the albite molecule and all the potash in the orthoclase molecule, they would respectively compose 42 and 35.3 per cent of the rock. Both these figures must be slightly too high. The result of the whole calculation shows the following approximate composition:

	Per cent.
Albite molecule	41.0
Orthoclase molecule	35.0
Quartz	11.0
Hornblende	5.0
Anorthite molecule	4.0
Magnetite	1.8
Apatite	0.4
Zircon	0.2
Biotite, titanite, diopside, and allanite	1.6
	100.0

Three determinations of the specific gravity of the rock gave an average of 2.659 at 17° C.

The geological relations, structure, and constitution of this phase clearly place the rock among the alkaline quartz-syenites, closely allied to the nordmarkites of Tonsenås and other localities in the Christiania region (compare cols. 1, 3, and 6). Brögger's table gives the limiting values in the percentage composition of nordmarkite. Two other American examples are noted in columns 7 and 8.

Phase g.—The porphyritic phase of the stock is widespread, especially on the east and southeast sides of the mountain. The rock is structurally, but neither chemically nor mineralogically, except as regards some of the accessories, to be distinguished from the normal equigranular type. This second phase is exhibited on a large scale on the prominent bald knob east of the main summit.

The color of the rock is always a light gray or pinkish gray, which is stable and does not change to green on exposure (spec. 115). The phenocrysts are almost always roundish feldspars which may reach the diameter of one centimeter or more; much more rarely a hornblende or augite individual will approach the same dimension. The phenocrystic feldspars are microperthite, orthoclase, albite, and oligoclase, often arranged in groups of two or more large individuals. The first named is probably the most abundant, but is much less predominant than in the granitic phase on account of the greater amount of free albite and oligoclase. The orthoclase, to judge from its typical specific gravity (2.594 at 16° C.), must contain considerable soda in intimate mixture. The acid oligoclase and albite are often surrounded by a thin mantle of orthoclase, which is thus later in origin. Microcline is probably present among the phenocrysts, but is quite rare.

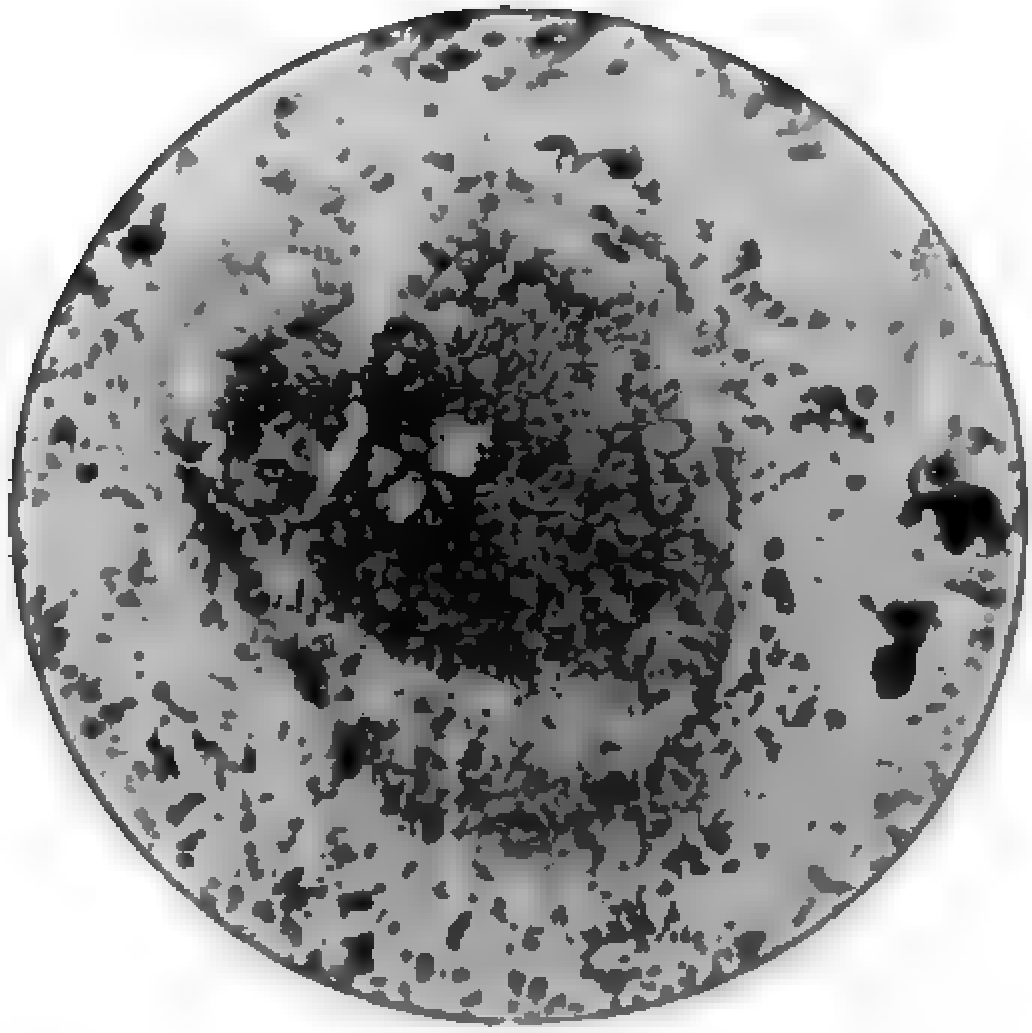
The groundmass is a hypidiomorphic pepper-and-salt mixture of the same essential minerals as in phase *f*. The diopsidic augite, brown hornblende, and the biotite are more abundant than in that phase, causing the specific gravity of the rock to be higher (here 2.685 at 17° C.). The augite, as in the phenocrysts, seems always to occur as cores in intergrowths with the primary hornblende. Corrosion of the dark-colored silicates is much less pronounced than in the granitic phase; they exhibit, correspondingly more often, idiomorphic outlines. Free quartz in the form of small interstitial grains occurs, but is not so prominent an accessory as in phase *f*. Titanite is here more abundant, and explains the somewhat higher percentage of TiO_2 in the analysis. The higher MgO is ascribed to the more abundant biotite.

The rock shows no indications of crushing; we can not, therefore, attribute the porphyritic structure to cataclastic processes. The groundmass has unquestionably crystallized in its present form from an igneous magma. The order of crystallization of its component minerals is the same as in the green rock. Several facts favor the view that the feldspar phenocrysts belong to an earlier stage in the crystallization than that which produced the groundmass.

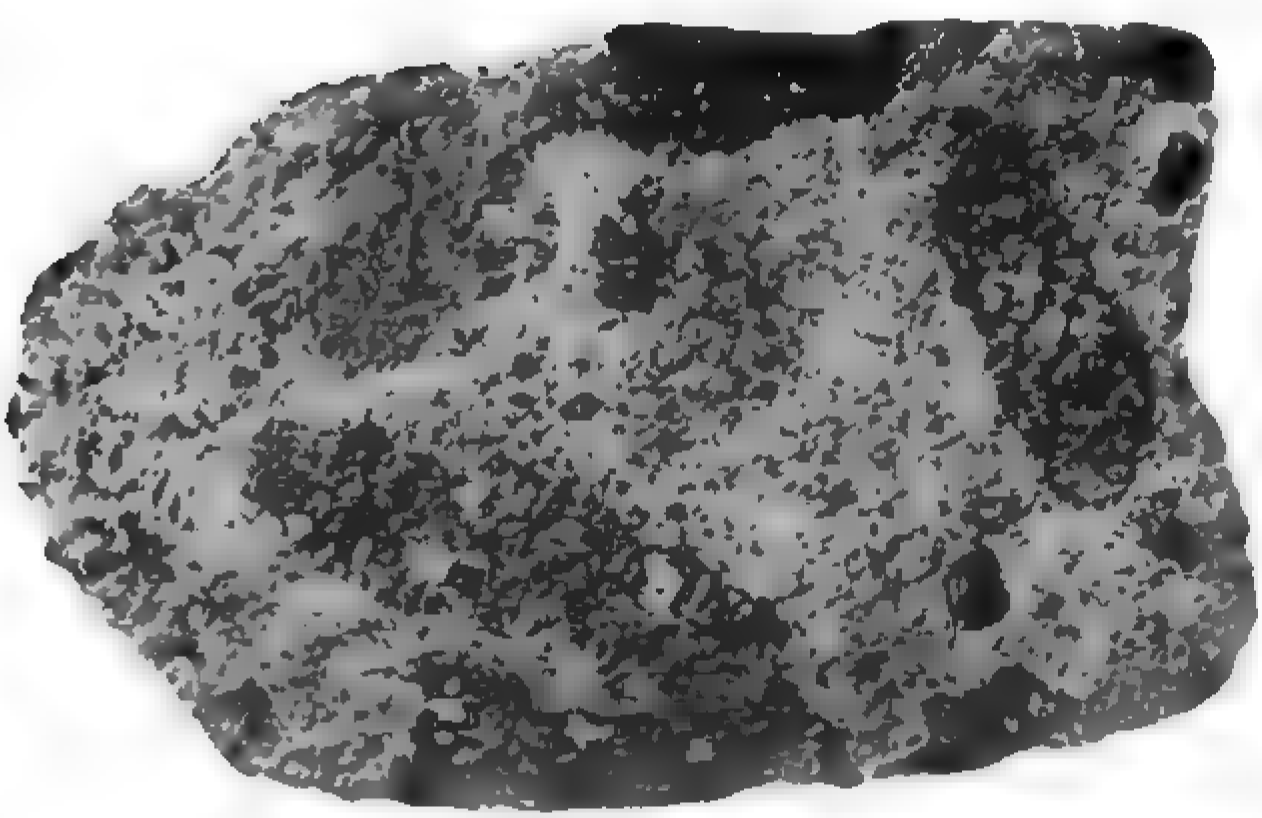
PLATE V.

A, Segregation of mica and hornblende concentrically arranged, in paisanite (the same section of the segregation also appears in the lower right-hand quadrant of the micrograph represented in Pl. IV, *B*); ordinary light, × 24. (See p. 72.)

B, Basic segregations in nordmarkite at Crystal Cascade; one-half natural size. (See p. 64.)



(A)



(B)

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Feldspars of similar nature and size are abundant in the basic segregations with which this phase is richly charged, and with them are granitic groupings of several individuals separated by interstitial quartz. The segregations are mostly composed of those minerals of the groundmass which crystallize out in an early stage of consolidation. The large feldspars and the groups would thus antedate that groundmass. The feldspar phenocrysts which are mantled with orthoclase very often present the appearance of having been extensively corroded by the magma before the mantles grew about them. It is probable, also, that there were two generations of the bisilicates. The granitic groupings of large individuals suggest that the porphyritic structure may be largely due to protoclastic action breaking up a coarse-grained granitic rock already more or less completely solidified in the conduit when the somewhat later magma of the "groundmass" was erupted. On the other hand, we can not exclude the possibility that this phase is the result of chilling, developing a porphyritic structure equivalent to that which may be seen in the endomorphic zone and in the apophyses of the granitic phase; for it is often impossible to distinguish hand specimens of the latter rocks from typical specimens of phase *g*. The problem thus merits further inquiry.

One of the most peculiar features of the syenites which may be seen in all the phases, but is best exemplified in this particular phase, is the presence in the rock of numerous dark, roundish spots or kernels. These vary from 1 millimeter to 1 centimeter in diameter. They occur in all parts of the rock, but are specially abundant in the basic segregations, which will be more fully described hereafter. The kernels belong to two classes, which show the common characteristic of a core and mantle structure. Within a relatively thin black outer covering of felted, often radially arranged, biotite (and less conspicuously hornblende) there is a core of variable composition. The latter may be composed entirely of chlorite and magnetite; of chlorite, magnetite, biotite, and a uralitic amphibole; or entirely of a light-green pleochroic actinolitic hornblende. The last mentioned is the commonest type of core.

The mantle is to be regarded as a reaction rim. The chloritic cores are the product of the alteration of augite, probably in consequence of metasomatic action. The actinolitic kernels are likewise plainly derived, but in no one of some twenty-five slides could there be found a remnant of the original mineral at the heart of the kernel. The similarity in size and general relations between these and the chloritic kernels suggest that augite was here, too, the original material from which the hornblende felt was constructed. The freshness of the biotite rim, the absence of secondary ore and chlorite, and the complete freshness of the hornblende core lead to the conclusion that the alteration took place before or during the consolidation of the rock.

This class of kernels would thus fall into the class of magmatic pseudomorphs after pyroxene. One is reminded of the analogous ocellar alteration of olivine into hornblende.

Chemically this phase is practically identical with the green granular rock (cf. columns 1 and 2 in Table VII). Mineralogically the similarity is almost as close. The only important difference is in the structure. Phase *g* may then be classified as a *nordmarkite with a porphyritic habit.*

BASIC SEGREGATIONS.

Every observant visitor to Ascutney is struck by the extreme richness of the Main syenite stock in basic inclosures of generally a nodular form, and he might also note that they are more abundant in the porphyritic phase than elsewhere (Pl. V, *B* and Pl. VI). They are distributed with great irregularity. Sometimes they occupy as much as one-half of the volume of the rock, if one may judge from the appearance of even broad ledges. At other times the nodules are separated by many feet or yards of the normal rock. Partly on account of their abundance in erratics won from the mountains a well-defined glacial bowlder train has been shown by C. H. Hitchcock to exist in the lee of Mount Ascutney.[a] The nodules are dark gray to dark greenish gray in color, spheroidal or ellipsoidal in shape as a rule, and of all sizes up to those occupying several cubic feet. The section of one of them, outcropping near the contact with the granite at the southeast end of the mountain, was found to measure 2 by 10 feet. While the much darker color causes the nodules to be in striking contrast with the normal rock in hand specimen or in ledge, microscopic study proves an intimate dovetailing and interlocking of the minerals between the two. The nodule has not been enriched in the bisilicates by the special impoverishment of the matrix immediately surrounding, for in no case could there be found a zone about the nodule distinctly lighter in color than the normal rock. This is the more difficult to understand because of the very evident lack of flow structure in the rock as a whole. The nodules seem to have formed quietly in the magma after it had suffered its "mise en place" and not to have been disturbed in position since. Even those which are decidedly elongated do not show the degree of common orientation which we should expect if they had floated in a streaming fluid matrix.

The nodular masses are themselves porphyritic. Large, irregularly bounded crystals of microperthite, cryptoperthite, microcline, orthoclase and plagioclase (averaging acid labradorite Ab_1An_1), green hornblende, and the usual diopsidic augite, with or without a hornblende mantle, form the phenocrysts (see Pl. V, *B*). The dark matrix is a fine-grained granular, panallotriomorphic mass of hornblende, oligo-

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[a] Bull. Geol. Soc. Am., Vol. I, 1890, p. 30.

BASIC SEGREGATIONS AND INCLUSIONS OF SCHIST IN NORDMARKITE AT CRYSTAL CASCADE.

clase, biotite, and quartz, with abundant grains or idiomorphic crystals of titanite, ilmenite, apatite, and zircon. The microperthite and labradorite of the phenocrysts and the hornblende, biotite, and oligoclase of the groundmass are really the essential constituents. The pleochroism of the hornblende seems to indicate that it is less alkaine than the amphibole of the matrix.

a, pale yellowish green.

b, grayish green (absorption medium to strong).

c, grass-green to leek-green (absorption medium to strong).

b = **c** > **a**.

As already noted above, these segregations characteristically contain light-colored, coarsely crystalline areas from 1 to 2 centimeters in diameter, similar in composition to the normal syenite of phase *f*, i. e. equigranular aggregates of alkali-feldspar and bisilicates. These have the appearance of having functioned as centers of crystallization during the growth of the nodule, although there is a complete absence of both radial and concentric structure in the nodules.[a] In no case was there observed an approach to the "Kugelstruktur" of the rock at Virvik or at the well-known Corsican locality.

The specific gravity of the average segregation is near 2.850, and is thus considerably higher than that of the matrix, and still higher than that of the molten magma which represented the yet uncrystallized matrix. Unless that matrix possessed a high degree of viscosity during the formation of the nodules, they must have sunk down in the magma, and we might expect to find them concentrated in the lower part of the conduit; yet they appear to be distributed in about equal average proportion in all parts of the stock where the porphyritic phase was found, whether at the summit or 2,000 feet vertically below. This fact agrees with the absence of flow structure in the rock in forcing us to take the view that the segregations do not belong to the preeruptive period, as advocated by Lacroix, Michael Lévy, Graber, and others for other occurrences. The nodules had best be referred to an early stage in the actual consolidation of the syenite already occupying its conduit.

The accompanying Table VIII (col. 1) shows the analysis of the average segregation from phase *g* (spec. 66). Columns 3, 4, and 5 give, for purposes of comparison, the analyses of classic essexite, classic monzonite, and an average diorite.

The essential mineralogical composition of these rocks is as follows:

1. Oligoclase, microperthite, cryptoperthite, acid labradorite, microcline, orthoclase, hornblende, biotite, augite.

2. Microperthite, hornblende, orthoclase.

3. Labradorite, orthoclase (nepheline), augite, biotite, barkevikitic hornblende (olivine).

4. Orthoclase, oligoclase, andesine, labradorite, augite, green hornblende, biotite.

[a] Cf. Chrustschoff, Mém. Acad. imp. sci. St. Pétersbourg, Ser. VII, Vol. XLII, No. 3, 1891, p 86.

TABLE VIII.—*Analyses of basic segregations, etc.*

	1.	2.	3.	4.	5.
SiO_2	56.51	56.53	47.94	55.88	56.52
Al_2O_3	16.59	16.47	17.44	18.77	16.31
Fe_2O_3	1.35	1.58	6.84	[a]8.20	4.28
FeO	6.59	5.40	6.51		5.92
MgO	2.52	2.67	2.02	2.01	4.32
CaO	4.96	4.90	7.47	7.00	6.94
Na_2O	5.15	5.59	5.63	3.17	3.43
K_2O	3.05	3.80	2.79	3.67	1.44
H_2O above 110° C	0.71	0.60	2.04	1.25	1.03
H_2O below 110° C	0.21	0.23			
CO_2	0.33	0.05	------	------	------
TiO_2	1.20	1.40	0.20	------	0.25
ZrO_2	0.04	0.03	------	------	------
P_2O_5	0.41	0.27	1.04	------	0.40
Cl	0.07	0.07	------	------	------
F	0.24	0.19	------	------	------
FeS_2	0.06	Trace	------	------	------
NiO, CoO	Trace?	Trace	------	------	------
MnO	0.24	0.20	------	------	------
BaO	0.03	Trace	------	------	------
SrO	Trace	Trace	------	------	------
Li_2O	Trace	Trace	------	------	------
	100.26	99.98	99.92	99.95	100.98
O=F, Cl	0.11	0.09	------	------	------
	100.15	99.89	------	------	------
Total S	0.03	Trace	------	------	------
Sp. gr	2.849	2.756	------	------	------

[a] With MnO.

1. Basic segregation in phase *g* of Main nordmarkite stock; analysis by Hillebrand.
2. Basic segregation in dike of hornblende-paisanite, Ascutney Mountain; analysis by Hillebrand.
3. Classic essexite, Salem Neck, Salem, Mass.; analysis by Dittrich.
4. Average analysis of monzonite, according to Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 39.
5. Average analysis of sixteen typical diorites, according to Brögger, ibid., p. 37.

There is a relationship of the segregation with each of these types, though that with monzonite is the closest. The writer has seen in the laboratory of M. Fouqué, in Paris, thin sections of monzonite from

Predazzo, made from a contact phase of that rock. The structure and the small proportion of monoclinic feldspar showed close similarity of this phase of the monzonite with the Ascutney segregations.

Two other phases of the Main stock may be noted, not only on account of their importance in the field but also because they represent interesting extremes in the differentiation of the syenitic magma.

Phase h outcrops extensively in a belt about 400 yards (366 meters) wide and adjacent to the contacts with diorite and gneiss on the northwest side of the mountain. It is probably a special part of the endomorphic zone of the stock, as the phase has not been found anywhere else than in the belt specified (spec. 34). This member of the rock body is composed essentially of microperthite, usually in Carlsbad twins, and an amount of quartz sufficient to place the rock among the granites. Biotite, diopside, zircon, and magnetite are the accessories, but make up probably no more than 1 per cent of the rock. One grain of garnet, another of what is doubtless corundum, two individuals of a brown hornblende, and a few needles of apatite were discovered in the two sections that have been prepared from this phase.

The original color of the rock is due to the feldspar and is a striking dark oil green, which is permanent in the hand specimen, and doubtless represents a late stage in the series of color changes already described for the quarry rock. The structure is often fluidal or trachytic as governed by the tabular feldspars.

To form an idea of the relative proportions of the soda and potash molecules in the rock the specific gravity of some thirty cleavage pieces of the feldspar was determined. Specific gravity could be safely relied upon on account of the freshness of the rock and on account of the lack of inclusions in the feldspar. The average for the thirty pieces was 2.594 at 22° C.; the range of specific gravity was from 2.582 to 2.612. The extinction angles showed that the albite of the intergrowth is nearly pure and has only a very small intermixture with the lime molecule. Accepting Brögger's values for the specific gravities of pure albite and pure orthoclase the average for this rock corresponds to a microperthite in which the two silicates occur in about equal proportion, with the albite the more abundant. The specific gravity of the rock is 2.616 at the same temperature. If we assume that the ratio Ab:Or=41:35 as in the granitic phase, that the lime is 1 per cent of the rock and the accessories 1 per cent, there would be about 20 per cent quartz in the rock. This rough estimate agrees with that made by inspection of the thin sections. This phase is thus a true *alkaline granite* at the extreme end of the series which leads to a rock with the composition of an aplite while preserving the hypidiomorphic-granular structure. A very similar rock occurs near Stratford, N. H., Albany, N. H., and Stark, N. H. These are illustrated in the collection of Professor Rosenbusch at Heidelberg. They all possess a higher proportion of bisilicates than phase *h*.

Another variety of true granite, into which the syenite is transitional, outcrops at the main summit of the mountain. It has the ordinary pinkish color of the average syenite of the stock. The composition is essentially the same as that just described for phase *h*.

Phase i.—Near the most westerly triple contact of granite stock, syenite stock, and phyllites, a fourth phase of the syenite was speedily noted in the field as unlike all the others in bearing an unusual amount of dark-colored minerals (spec. 111). The light-gray feldspars still give the dominant tone of color to this phase, which is also alkaline. The structure is that of phase *f*, equigranular; the grain is somewhat coarser. Basic segregations fail altogether or are very rare. The chief mineralogical difference between this phase and the others is found in the character of the feldspars. Triclinic feldspar is now one of the chief essentials. It varies in composition from the labradorite Ab_3An_4 to the andesine Ab_4An_3. Microperthite and orthoclase, hornblende, diopside, and biotite, with the properties of these minerals in phase *f*, are the other essentials; the same accessories are found here excepting allanite, monazite, and garnet. In addition there is a second hornblende among the essentials, with the following scheme of pleochroism and absorption:

a, Yellowish brown.
b, Deep brown to black, with specially strong absorption.
c, Deep brown, with a trace of olive-green.

$\mathbf{b} > \mathbf{c} > \mathbf{a}$.

The augite occurs only as cores in intergrowth with hornblende. Quartz is very subordinate among the accessories.

The basic character of this phase, its richness in bisilicate, the presence of much essential andesine-labradorite, coupled with the alkaline habit of the rock, are properties which relate the rock closely to *monzonite*. The resemblance of the Ascutney hand specimens and those from the classic locality of Mount Mulatto is very striking.

ENDOMORPHIC ZONE OF THE SYENITE STOCK.

All four phases of the stock are habitually more acid near the contact than elsewhere. Free quartz is even macroscopically so dominant that the contact rock stamps itself as a true granite. The usual chilling phenomena occur within a narrow zone not more than 20 feet across. Three feet from the contact the feldspar and quartz become idiomorphic and are embedded in a microcrystalline, often granophyric, groundmass, and a granite-porphyry is thus developed. Apophyses fail to show as much bisilicate as the parent rock body, have more free quartz, and tend toward the structure of a typical aplite. Excellent examples may be studied among some thick sheets on the north slope of the mountain, below the quarry. This endomorphic increase of silica is

paralleled in the Christiania region, where augite granite occurs as the contact phase of augite syenite rich in nepheline.[a]

GREAT SYENITE-PORPHYRY DIKE OF LITTLE ASCUTNEY MOUNTAIN.

The stock-like dike to which Little Ascutney chiefly owes its existence is remarkable for following in its general east-west course the zone of contact between the diorite and gneiss (Pl. VII and fig. 1). Throughout its whole extent the south wall of the dike is schist and the north wall is either diorite or the green dike mapped as "paisanite." This replacement of the zone of contact rocks by a later intrusive is undoubtedly due to the weakness of that zone, which is elsewhere evident in the extensive brecciation and crumpling of the schistose rock. Small apophyses from the dike into both schist and diorite clearly prove the syenite-porphyry to be the younger rock.

The dike is quite uniform in composition from end to end, though there is a coarsening of grain from the walls toward the center. The rock is almost the exact equivalent of the average porphyritic phase of the Main syenite stock, and a detailed description is therefore unnecessary (spec. 76). Hornblende and biotite are the essential dark-colored minerals. They and the feldspars again display a great amount of magmatic corrosion; this caustic action is here, as so often elsewhere in alkaline rocks, responsible for the rarity of idiomorphic boundaries among the phenocrysts, as, indeed, it may be responsible for the general rarity of porphyritic dike representatives of the alkaline magmas as a whole. Plagioclase seems to be entirely absent from this rock except in the form of a few rare phenocrysts of an acid oligoclase. Microperthite is not so abundant, either in the groundmass or among the phenocrysts, as it is in the porphyritic phase of the Main syenite stock.

The dike is to be classified as a *nordmarkite-porphyry*.

Dark patches of basic material are very common in this dike. They are roundish in form and vary from a fraction of an inch to 3 or 4 inches in diameter. In color and general macroscopic appearance they are similar to the nodules from phase *g* in the Main stock. The correspondence is more fully shown in the thin section. The same constituents are present as in the typical segregation of the Main stock and in the same relative amounts. That exception is significant. Both in the phenocrystic constituents and in the groundmass of the nodule microperthite is not so abundant as in the nodules from phase *g*. This fact indicates another proof of close sympathy between nodule and host and of the indigenous origin of the latter. The nodules themselves add another evidence to the community of origin between this dike and the Main stock. There can be little doubt that the two intrusions were products of essentially contemporaneous eruptions from a common magma.

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[a] Zeit. für Kryst., Vol. XVI, 1890, p 327.

SYENITE STOCK OF PIERSON PEAK.

The same may be said of the small stock of Pierson Peak. The plan of this rock body is elliptical. The longer axis measures 400 yards (366 meters), running about N 70° E; the minor axis measures 175 yards (160 meters). Coarse-grained apophyses prove the intrusive origin of the rock. It is uniformly a coarse-grained, light gray to light pinkish-gray alkaline syenite, with a proportion of dark colored constituents which is low even in comparison with the phases of the Main stock (spec. 62). The structure is the typical hypidiomorphic-granular, the order of crystallization that of phase *f* of the Main stock. Microperthite, orthoclase, and biotite are the essentials. Quartz, hornblende, augite, apatite, and zircon are all notably rare accessories; more important are titaniferous magnetite and titanite, the latter being unusually abundant. Basic segregations fail altogether or are extremely rare. The endomorphic zone is characterized by an almost complete lack of colored constituents and of quartz.

All the minerals have the same characters as in the granular phases of the Main stock. The rock is a nearly quartzless biotite-nordmarkite, or *pulaskite*. The writer proposes that the existing difficulty of differentiating these two rock types (compare cols. 4 and 5, Table VII, p. 59) be obviated by confining the name "pulaskite" to a rock which is in all other respects the equivalent of the nordmarkites except in the absence or subordination of accessory free quartz among the constituents. Excepting for a higher proportion of bisilicates in the Arkansas syenite, it would be hard to distinguish macroscopically this Ascutney rock from the classic pulaskite of Fourche Mountain; there is similar close parallelism with a geographically remote occurrence of the same type—that of Portella des Eiras at Monchique, Portugal.

APLITIC DIKES CUTTING THE SYENITES.

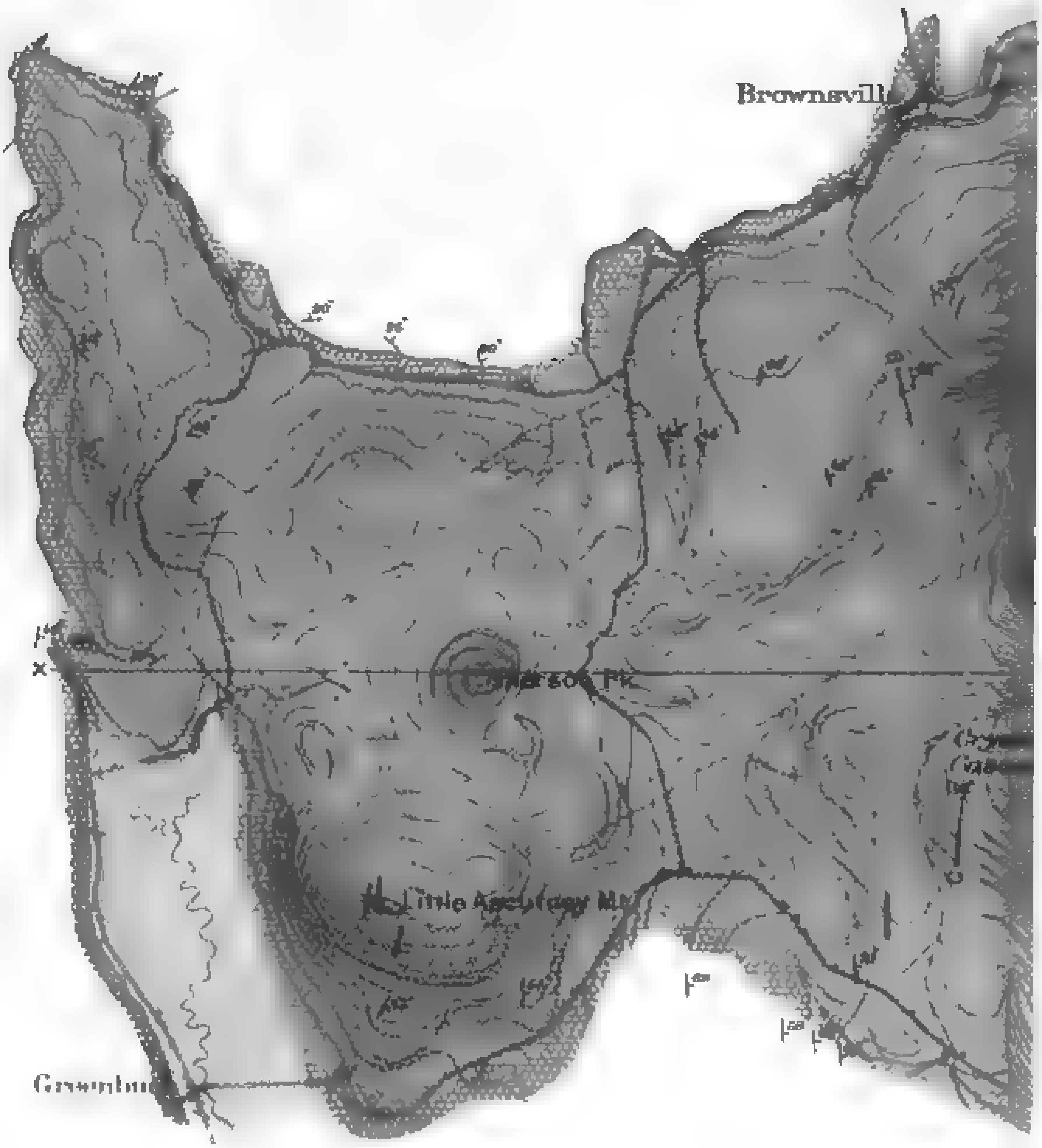
Three kinds of acid dikes have been found cutting the various syenites of the area. Two of these are intimately related to the stock phases; the third has variant features. It may be noted that there is an unusual lack of pegmatite veins both in the syenites and elsewhere about Ascutney.

PAISANITE DIKE CUTTING THE MAIN STOCK.

On the logging road running up from a sawmill on the northwest slope of Ascutney Mountain proper, toward the main summit, a dike was discovered in the dark-green granular phase *f* of the Main stock at about the 1,600-foot contour (see Pl. VII). The general trend of the dike is northeast-southwest, but at the road it bifurcates into two branches—one, 40 feet (12 meters) wide, striking N. 40° E.; the other, 50 feet (15 meters) wide, striking N. 25° E. The dike, as a whole, is visible only for about 100 yards (91 meters); at each end its continuation is lost in the underbrush and talus of the steep mountain side.

U.S.GEOLOGICAL SURVEY

SECTION THROUGH PIERSON PE

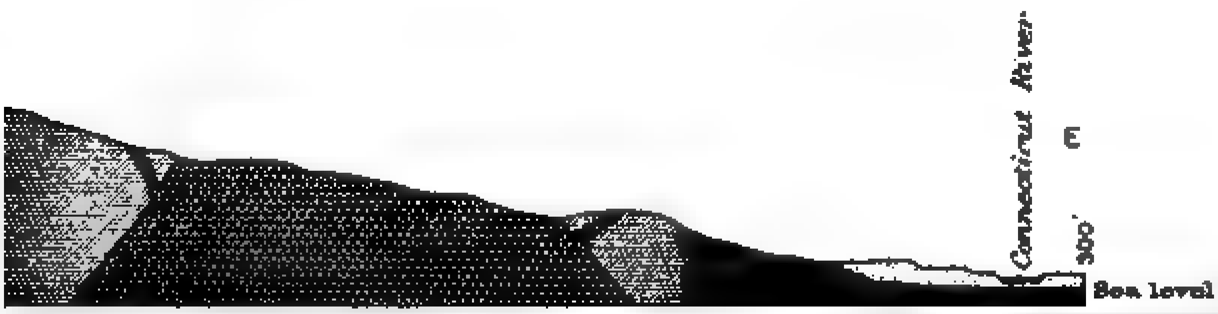


GEOLOGIC MAP
OF
ASCUTNEY MOUNTAIN AND VICINITY, VER

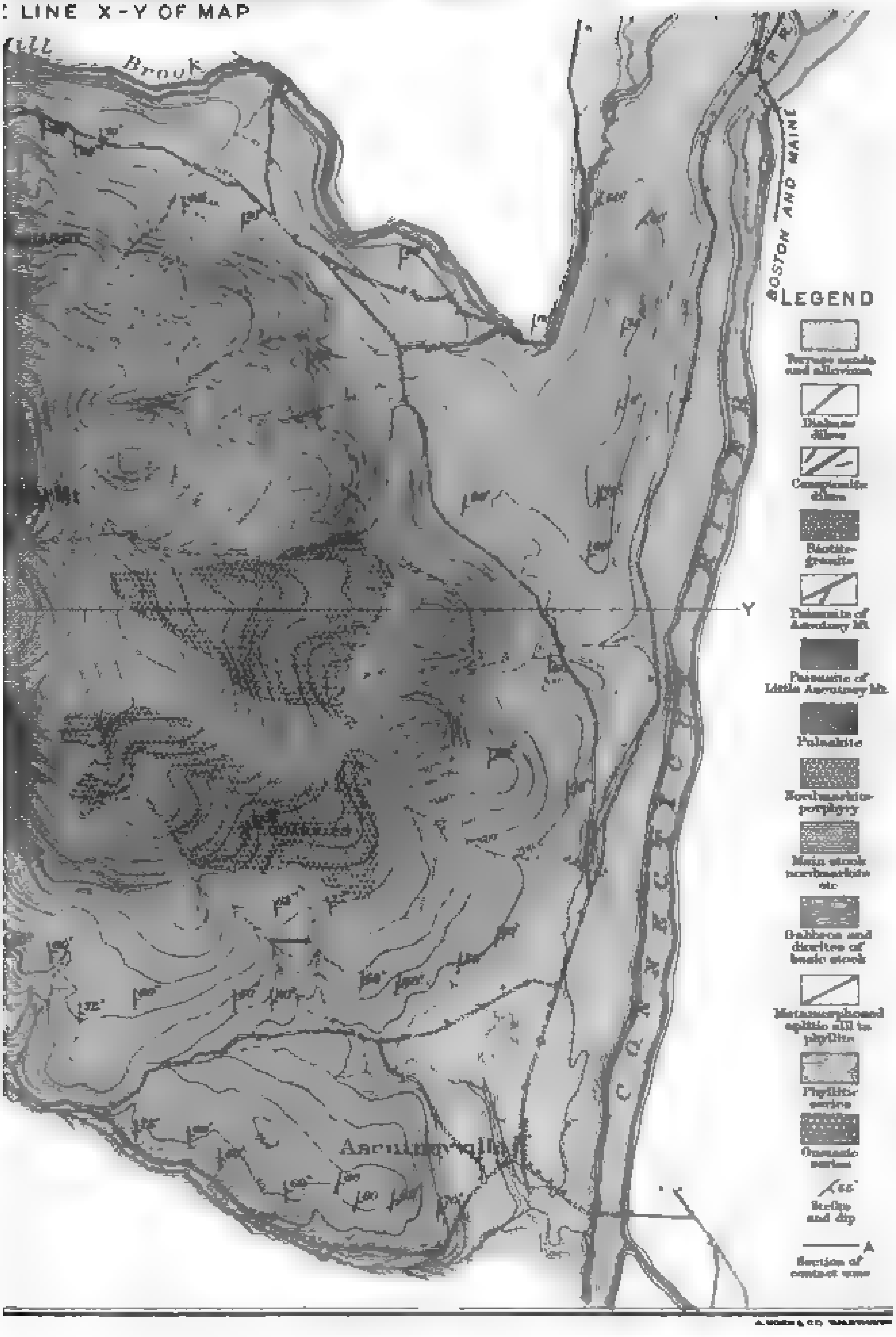
Geology by R. A. Daly
Topography by F. P. Gulliver

Scale

1 mile



LINE X-Y OF MAP



The rock is a light-tinted, pinkish-gray, pepper-and-salt, fine-grained, somewhat porphyritic aggregate of microperthite, soda-orthoclase, quartz, and alkaline hornblende, abundantly charged with basic segregations, with kernels of biotite and hornblende, and with pyroclastic feldspars won from the coarse syenite through which the dike passed during intrusion (spec. 139). The general habit is suggestively like that of the porphyritic phase *g* of the Main stock, and we must believe that the two are products of the same magma. Yet, as we have seen, the implication that phase *f* and phase *g* are of different ages (the former being cut by the latter) does not agree with the fact of observation in the field. It is probable that there was not a great interval of time between the intrusion of the Main stock and that of this dike.

The dike is characterized by a conspicuous platy structure due to jointing, and, near its walls, exhibits, for the space of a foot or two from the contacts, a strong fluidal character which is the more pronounced as the basic segregations have shared in the movement and are pulled out in long, dark-colored streaks in the dike.

The phenocrysts are either microperthite or, more rarely, orthoclase; they are specially abundant and are difficult to distinguish from the pyroclastic feldspars. The texture of the rock is really controlled by the groundmass, the structure of which is aplitic or panallotriomorphic. It is composed of microperthite, quartz, and brown hornblende, with properties identical with those of phase *f* in the Main stock. The hornblende always occurs in the form of small, poikilitic, and greatly resorbed grains. No biotite, diopside, or plagioclase were discoverable. Titanite, ilmenite, zircon, and apatite are, as usual, the accessories.

The pyroclastic feldspars are of special interest. They occur as single individuals or as groups (with interstitial quartz) of the same structure and grain as the country rock of the dike itself. Close study in the field showed conclusively that they are of pyroclastic origin. Their presence in the still unconsolidated dike affected its crystallization, so that many of these foreign feldspars are surrounded by typical reaction rims of material considerably more basic than the average groundmass of the dike. The usual appearance of the feldspar inclosure with its basic aureole is illustrated in Pl. IV, *B* (p. 58). The feldspar in this case is soda-orthoclase, and in the reaction of the extensively corroded feldspar with the matrix, the bisilicate of the reaction rim is even more strongly charged with soda than the brown hornblende of the average groundmass. The rim is an interlocking aggregate of microperthite and amphibole, with abundant magnetite and some zircon and apatite. The amphibole has bluish tones, as indicated by the scheme of pleochroism and absorption.

a, brownish yellow.
b, deep blue-green.
c, deep chestnut-brown, with a tinge of blue on the edges.
b>**c**>**a**, or perhaps **b**=**c**>**a**.

The extinction $c:\mathfrak{c}$ is about 19°.

This same hornblende forms minute basic segregations varying in size up to 1 or 2 millimeters in diameter. These lie in the general groundmass of the dike, and are not directly connected with the pyroclastic feldspars. Other segregations or replacements which recall the "kernels" of the Main syenite, and yet show somewhat different composition and structure, also occur in the groundmass. One of these is illustrated in Pl. V, *A* (p. 62). It is composed entirely of a faintly pleochroic, yellow to light-brown, biotitic mica arranged in alternating concentric zones with a blue hornblende. The pleochroism of the latter is:

> **a**, pale straw-yellow.
> **b**, deepish green-blue.
> **c**, blue, with a trace of green.
> **c** about=**b**>**a**.

The origin of these concentrically arranged mica-hornblende aggregations has not yet been determined. Their resemblance to the kernels of the Main syenite, which have been interpreted as magmatic pseudomorphs, is only partial. Especially difficult of understanding is the recurrence of the zones of mica and hornblende.

BASIC SEGREGATIONS.

The usual basic segregation of the dike is very similar to that in the porphyritic phase of the Main syenite (spec. 141). It is a dark-gray, mottled aggregate of phenocrysts and pyroclastic feldspars surrounded by a dense, granular groundmass of panallotriomorphic brown hornblende, microperthite, and orthoclase. Here there can be no doubt that the segregation grew under the directing influence of the large feldspars now seen within their mass, for the segregation of basic material is decidedly more pronounced in the immediate vicinity of the feldspars than elsewhere in the nodules. The nodules vary in size up to 2 or 3 inches (5.2 to 7.8 cm.) in diameter. In one slide a large crystal of pale-green augite with a mantle of green hornblende was found, suggesting that, after all, the kernels of this rock may have been derived from that mineral through magmatic influences. The hornblende of these larger segregations has a bluish cast, and seems to belong to a variety of amphibole intermediate between the hornblende of the reaction rim described above and the normal hornblende of the Main syenite. The specific gravity of a typical segregation was found to be 2.756; that of the parent rock, 2.633.

The chemical analysis of the average matrix in which the basic segregations lie is given in the Table IX, col. 1, p. 75; that of an average segregation from the dike is entered in Table VIII, col. 2, p. 66. The structure and composition, both mineralogical and chemical, relate the dike most intimately with *paisanite*, as described by Osann

(see Table IX, column 5). If we assume that there is 5 per cent of soda in the hornblende, and that that mineral makes up 3 per cent of the rock (a fair estimate after inspection of the slide), the mineral composition of the rock can be thus roughly determined as the following:

	Per cent.
Albite molecule	36.4
Orthoclase molecule	29.6
Quartz	29.5
Hornblende	3.0
Titanite	.5
Other accessories	1.0
	100

The analysis of the segregation does not lend itself to calculation on account of the abundance of the hornblende, the constitution of which is unknown. The essential equivalence of this analysis and that of the basic segregation from phase *g* of the Main syenite is striking. Again, among normal rocks, we must go to the monzonites for the nearest allies, chemically speaking, to these nodular masses. Mineralogically, the greatest difference between segregation and its matrix is found in the absence of triclinic feldspar in the former.

COMMON MUSCOVITE-APLITE OF THE MAIN STOCK.

Due south of the Windsor quarry, at the 2,350-foot contour, a dike about 1 foot (0.3 meter) in diameter traverses the syenite at a point where the latter is porphyritic and full of segregations. No other dike of the same composition has been discovered in the area, but it is highly probable that others exist. This dike is a typical aplite, a panallotriomorphic sugary mixture of quartz, orthoclase, and albite, with a little microperthitic feldspar and a few shreds of muscovite (spec. 191). The last mentioned mineral occupies certain areas in the thin section as if it is secondary after feldspar; in other cases, patches of matted quartz and muscovite represent the filling of small miaroles which are common in the rock. Numerous miarolitic cavities bearing terminated quartz crystals and muscovite plates are visible in the hand specimen.

PAISANITE DIKE ON LITTLE ASCUTNEY MOUNTAIN.

On referring to the plan of Little Ascutney intrusives (fig. 1) it will be seen that there is intercalated between the great syenite-porphyry dike of that ridge and the diorites on the north a second interrupted dike, which thus entered the same zone of weakness at the schist-contact as that earlier followed by the porphyry. This second dike is much smaller than the first, but measures, nevertheless, about 50 yards (46 meters) in width at the broadest part. It is probably this rock that was referred to by Hawes as the "granitell

of Little Ascutney."[a] It sends apophysal tongues into the diorite and is similarly believed to be younger than the porphyry, although only on account of the chilling phenomena observed in hand specimen and slide from the smaller dike where it is in contact with the other.

Hints as to the relationship of this dike are to be found in the ledge and hand specimen. When quite fresh the rock is a fine pale gray with a blue tone; in a few days it changes color to the same handsome olive-gray green which has been described as characteristic of the Windsor quarry rock. The resemblance between the two rocks is also manifest in the way in which they fracture, and in the peculiarly vibrant musical note given out when a large fragment is struck with the hammer. Certain of the finer-grained streaks in the quarry can hardly be distinguished from the green dike in the hand specimen.

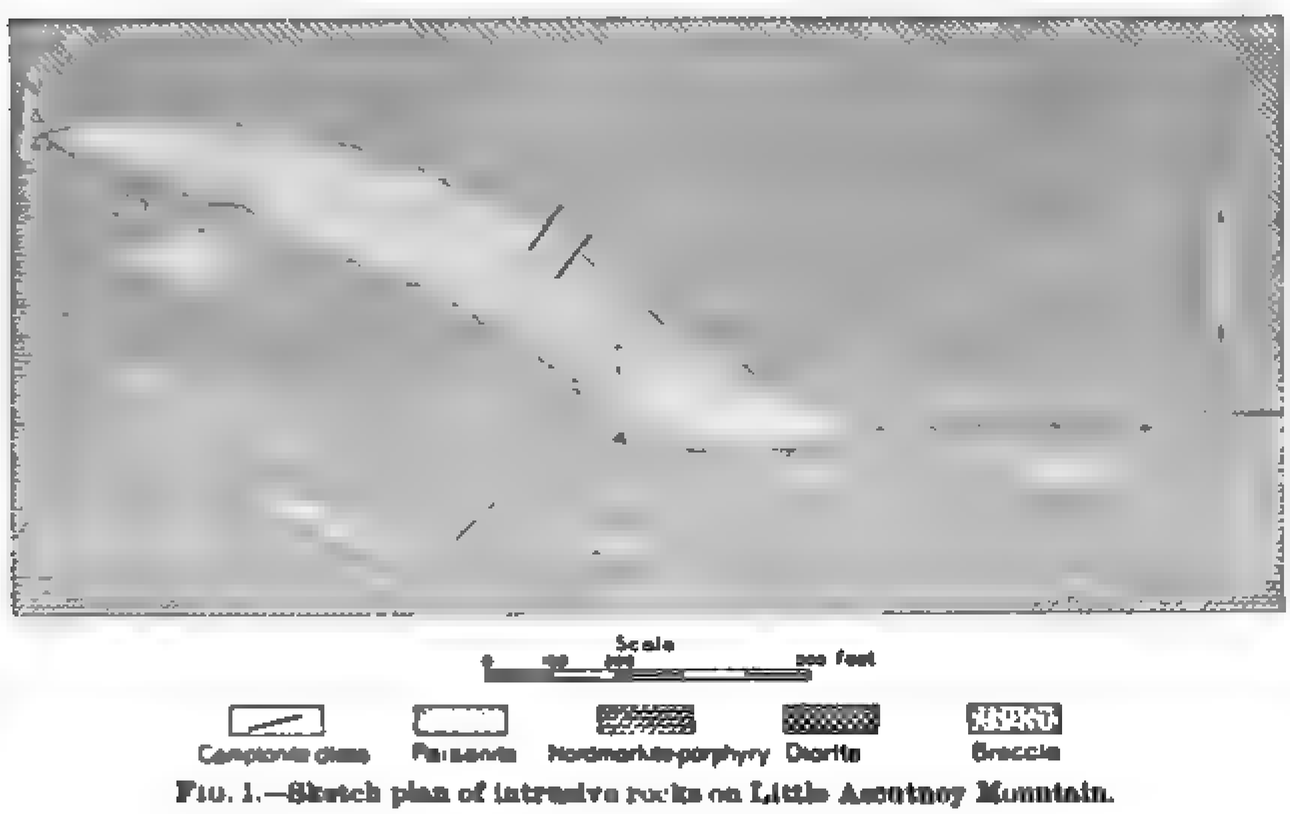


FIG. 1.—Sketch plan of intrusive rocks on Little Ascutney Mountain.

The rock is a very fine-grained typical aplite with a sugary, panallotriomorphic structure (spec. 60). The essential minerals are nearly the same as in the paisanite just described from the main mountain. Quartz is, however, quite prominent among the phenocrystic individuals which are otherwise composed of microperthite, either in separate crystals or in groups. The same constituents, with cryptoperthite and an alkali-iron hornblende identical in characters with that of the Windsor quarry rock, are the essentials in the groundmass. The quartz and feldspar "phenocrysts" are connected through all stages of transition with the same minerals of the groundmass, and it is probable that there has been but one generation of these essentials. The hornblende is strikingly poikilitic, as if corroded in the extreme. Biotite, oligoclase, magnetite, apatite, and zircon occur as accessories.

[a] Geology of New Hampshire, Vol. III, part 4, 1878, p. 183.

TABLE IX.—*Analyses of paisanites and other rocks.*

	1.	2.	3.	4.	5.	6.
SiO_2	73.69	73.03	77.14	66.50	73.35	70.19
Al_2O_3	12.46	13.43	12.24	16.25	14.38	11.96
Fe_2O_3	1.21	0.40	0.29	2.04	1.96	4.94
FeO	1.75	1.49	1.04	0.19	0.34	1.18
MgO	0.17	0.14	0.06	0.18	0.09	0.16
CaO	0.36	0.79	0.35	0.85	0.26	0.65
Na_2O	4.47	4.91	4.64	7.52	4.33	5.73
K_2O	4.92	4.54	4.47	5.53	5.66	4.06
H_2O above 110° C	0.24	0.35	[a]0.14	[a]0.50	--------	--------
H_2O below 110° C	0.14	0.18				
CO_2	Trace	Trace?	--------	--------	--------	--------
TiO_2	0.28	0.30	0.29	0.70	--------	--------
ZrO_2	0.14	0.06	--------	--------	--------	--------
P_2O_5	0.04	0.06	--------	Trace	--------	--------
Cl	0.02	0.03	--------	--------	--------	--------
F	0.05	0.08	--------	--------	--------	--------
FeS_2	--------	0.09	--------	--------	--------	--------
MnO	0.15	0.15	Trace	0.20	--------	0.48
BaO	--------	Trace	--------	--------	--------	--------
SrO	Faint tr.	Trace	--------	--------	--------	--------
Li_2O	Trace?	Trace	--------	--------	--------	--------
CuO	Trace	?	--------	--------	--------	--------
	100.09	100.03	100.66	100.46	100.37	99.94
O=F, Cl	0.02	0.04	--------	--------	--------	--------
	100.07	99.99	--------	--------	--------	--------
Total S	--------	0.05	--------	--------	--------	--------
Sp. gr	2.633	2.628	--------	--------	--------	--------

[a] Loss on ignition.

1. Hornblende-paisanite dike cutting Main syenite, Ascutney Mountain; analysis by Hillebrand.

2. Hornblende-paisanite dike cutting nordmarkite-porphyry, Little Ascutney; analysis by Hillebrand.

3. Lestivarite, Bass rocks, Gloucester, Essex County, Mass.; analysis by Washington, Jour. Geol., Vol. VII, 1899. p. 107.

4. Classic lestivarite, Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. III, 1898, p. 216; analysis by V. Schmelck.

5. Classic paisanite, Osann, Tscher. Miner. u. Petrog. Mitth., Vol. XV, 1896, p. 439.

6. Average grorudite, according to Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. I, 1894, p. 63.

The chemical analysis of this rock is given in Table IX, column 2, along with that of other rocks of related types. Their corresponding essential mineralogical composition is as follows:

1. Microperthite, soda-orthoclase, quartz, alkaline hornblende.
2. Microperthite, quartz, soda-orthoclase, alkaline hornblende.
3. Microperthite, other alkaline feldspar, quartz, hornblende, biotite.
4. Cryptoperthite, ægirine.
5. Microperthite, cryptoperthite, quartz, riebeckite.
6. Quartz, microperthite, microcline, albite, soda-orthoclase, ægirine, catoforite.

The molecular proportions for the Ascutney rock have been calculated as follows:

	Analysis.	Molecular proportions.
SiO_2	73.03	1.2165
Al_2O_3	13.43	.1313
Fe_2O_3	0.40	.0025
FeO	1.49	.0207
MgO	0.14	.0035
CaO	0.79	.0141
Na_2O	4.91	.0792
K_2O	4.54	.0484
TiO_2	0.30	.0036
ZrO_2	0.06	.0005
P_2O_5	0.06	.0004

If we suppose that the hornblende has 10 per cent lime, 3 per cent soda, and 40 per cent silica (not far from the proportions of those oxides in barkevikite), we can get an approximate idea of the quantitative mineral composition of the rock. On these suppositions the albite molecule would make up 40 per cent of the rock. The proportion of the same molecule would be 38 per cent if the hornblende were 5 per cent soda, and 41.5 per cent if all the soda were in the feldspar. The results of the calculation, based on an accurate knowledge of the composition of all the minerals, would not be far from the following:

	Per cent.
Albite molecule	40
Orthoclase molecule	27
Quartz	27
Anorthite molecule	2
Hornblende	3
Accessories	1
	100.0

A comparison of columns 1, 2, and 5 in Table IX shows at once the thorough similarity of this rock to classic *paisanite* and to the great

aplite dikes on the northwest side of the main mountain. The last mentioned we have seen to be an acid representative of the porphyritic phase of the Main stock; in the same way the Little Ascutney paisanite, in its composition, evanescent color, and freedom from basic segregations, is closely allied to the granitic phase of the same stock. Both of the Ascutney paisanites are allied to grorudite (column 6) and to the "lestivarite" of Essex County (column 3) which, however, is a type considerably divergent from classic lestivarite (column 4).

BRECCIA MASSES ON LITTLE ASCUTNEY MOUNTAIN.

Inclosed in the green paisanite dike are 2 horses of breccia, the larger measuring in plan 25 feet (7.5 meters) by 8 feet (2.4 meters). In the older adjoining syenite-porphyry dike there are at least 16 similar horses exposed on the crest of the ridge, as indicated on the sketch map (fig. 1, p. 74). The largest of the horses in the porphyry is 180 feet (55 meters) in length by 55 feet (16.5 meters) in breadth. The smallest one mapped covers 8 (2.4 meters) or 10 (3 meters) feet square, though many smaller fragments of the same rock occur scattered through the porphyry.

These interesting bodies were first described by the geological survey of Vermont. In its final report Edward Hitchcock developed a theory of the Ascutney eruptives which is founded on the discovery of the breccia. It can best be expressed in his own words:

> * * * If we ascend Little Ascutney, near its west end, on the top, just where the southern slope begins, masses of a conglomerate of a decided character, several feet and even rods wide, appear on the side of the porphyry and granite. All traces of stratification in the conglomerate are lost and it passes first into an imperfect porphyry, and this into granite without hornblende, in the same continuous mass, without any kind of divisional plane between them. Where the conglomerate is least altered it is made up almost entirely of quartz pebbles and a larger amount of laminated grits and slate, the fragments rounded somewhat and the cement in small quantity. It is easy to see that a metamorphism has taken place in all the conglomerate and some of the pebbles might even be called mica-schist. In the cement also we sometimes see facets of feldspar. In short, it is easy to believe that the process of change need only be carried further to produce syenite, porphyry, or granite. One can not resist the conviction that the granite rocks of the mountain are nothing more than conglomerate melted down and crystallized, or at least that such was the origin of part of them.[a]

Van Hise has dissented from this view and briefly stated his opinion that these "pseudo-conglomerates" are flow breccias. He says: "The matrices of these rocks are thoroughly crystalline granular granite, syenite, or porphyry. Thus they are eruptives which have caught within them fragments of the rocks through which they have passed."[b]

The observations of the writer do not agree with Hitchcock's determination of the relation between the horses and the porphyry. There

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[a] Geology of Vermont, 1861, Vol. II, pp. 565–566.
[b] Bull. Geol. Soc. Am., Vol. I, p. 236, footnote.

is no transition between the two, but instead a very clean-cut contact, which is just as distinct as that between the porphyry and the schists. The facts that lead to the rejection of Van Hise's theory of the breccia will also be briefly noted.

The horses do present in the field the general appearance of flow breccias (spec. 36). In thin section, however, the compact, dark greenish-gray cement resolves itself into an aggregate of clastic grains of quartz and feldspar in a secondary groundmass of argillaceous material, chlorite, biotite, and quartz. The biotite looks metamorphic and is concentrated about magnetite, which is comparatively abundant. Small garnets are also interspersed in the cement in great numbers, and, like the biotite, were, in all probability, formed in the partial alteration of the cement by the heat and mineralizers of the porphyry intrusion.

There can be no doubt that such a matrix is clastic, and the shape and nature of the inclosed fragments agree with that interpretation. They are subangular or angular and without visible stratification. In size they vary from those of microscopic dimensions to others having an area of a square foot or more. Usually the corners are sharp and plainly indicate that the fragments have not been worked over by water. As Hitchcock pointed out, these "pebbles" are of many different sorts.

The great majority of the fragments belong to the schists. A phyllite composed of quartz and sericite (occasionally with metamorphic biotite) as essentials, and of graphitic and iron ore with zircons as accessories, is very common. It is the slightly metamorphosed equivalent of the phyllite in the eastern half of the Ascutney area. The rocks of the contact aureole of the main mountain are also represented by many fragments that are still more altered forms of the phyllites than the type just mentioned. Certain of the dark, fine-grained blocks are made up essentially of cordierite rendered turbid by numerous microlitic inclusions, probably sillimanite. The gneissic fragments are usually of the varieties found in the fundamental formation at the foot of Little Ascutney. They are typical biotite-gneisses, often garnetiferous and sometimes charged with epidote. The mica-schist of the basal crystallines has a place in the breccia as a biotite-quartz-schist with little accessory material. An amphibolite, identical in composition with that described from the locality at the foot of Crystal Cascade, is likewise present among the blocks.

Quartz occurs as large, angular pieces from single crystals, as compact quartzite, and as a chalcedonic variety. Granular epidote with some quartz forms smaller fragments up to 1 inch (2.6 centimeters) in diameter, suggesting the equivalent of the metamorphosed limestone of the Ascutney contact zone. Large broken crystals of orthoclase are also common and are unquestionably fragmental in the same sense as the cement. So far as known, there is only one igneous rock among

the breccia fragments, and it is one of the least abundant kinds. It is a typical granite-porphyry with an ideal development of idiomorphic quartz and feldspar phenocrysts. The only dark-colored constituent is biotite, the lamellæ of which are always grouped after the manner of segregations and never seem to form true phenocrysts. This is the only component of the breccia which is not to be found in crystalline schists surrounding Ascutney. The breccia cement itself may be regarded as the comminuted remains of the broken-up schists.

Each of these great horselike inclusions is now seen to have the composition, structure, and possible field relations of a true fault breccia. The most satisfactory explanation of them would attribute them to the disrupting action of vigorous and long-continued differential movements in an ancient zone of dislocation. That zone was perhaps nearly coincident with the present course of the two large dikes in which the horses are embedded. The faulting gradually prepared the material and recemented it into a new, tough, solid rock. Later, the invading eruptives carried off large masses of it as they forced their way along the old zone of dislocation and consequent weakness. The average specific gravity of the horses is about 2.79; that of the syenite porphyry, 2.646. It is reasonable to suppose that the immersed blocks of breccia sank to their present position rather than that they were carried up from below.

BIOTITE-GRANITE STOCK.

The second of the stocks which go to make up the main mountain is much the smaller of the two. The total area is about 1 square mile (2.6 sq. km.). The highly irregular contact line touches both syenite and phyllites (see Pl. VII).

That this rock (an *alkaline biotite-granite*) must be referred to a period of intrusion different from that of the Main stock was a matter of somewhat prolonged study in the field. An early examination of specimens and outcrops indicated that on the southeast side of the mountain along the contact with the schists there were two points where the igneous rock changed from a quartzless hornblende-bearing phase to a highly quartzose phase, devoid of all dark-colored essentials save an occasional shred or plate of biotite. This change was in all cases sudden, and each phase held its character for a long distance from their common contact with the schists. A second visit to the same localities explained the true relations. It showed that the granite is not of the nature of an acid flow streak on a large scale in the syenite, but that the former was intruded after the syenite had consolidated. A characteristic endomorphic zone that developed in the granite will be described below. A slight amount of alteration in the syenite itself may be detected. It is of the nature of the formation of a secondary granophyric structure among the feldspars

of the once thoroughly granular syenite, but it is sufficient to emphasize here the granitic apophyses in the nordmarkite as a proof of the younger date of the more acid rock.

In one of these apophyses about 6 inches (15.2 centimeters) in width the walls of syenite must have been already solid when the granite was intruded, since out from them have been developed a large number of quartz prisms standing squarely on the walls and terminated with the usual planes at the free ends, which, of course, point toward the middles of the apophysis. The prisms average 3 or 4 centimeters in length by 1 centimeter in thickness. Other large crystals similar to these sessile ones are to be seen completely surrounded by the granitic matrix; they are doubly terminated. This apophysis, while thus allied to the pegmatites, is yet believed to be a true offshoot of the granite because of the identity of composition existing between its matrix and the material of the more normal apophyses. An analogy is to be found in a syenite dike cutting the classic laurvikite, wherein cryptoperthite crystals take the place of the large quartzes of the Ascutney dike.[a]

The granite has been mapped with a fairly close degree of accuracy. The very dense second-growth timber and a lack of outcrops prevented the discovery of the contact line in some places.

In three abandoned quarries situated in the southern lobe of the stock, about 250 yards (225 meters) from the schist contact, a more or less well-developed master jointage is to be seen. Its chief interest consists in the evident independence of this jointage and the present topography of the deep valley in which the quarries are situated. The latter lie on an east-west line. At the main quarry, in the middle, the joint planes dip about 15° south, or a few degrees east of south. At the eastern and western quarries they are found to swing into an easterly and westerly direction of dip respectively. In the western quarry the ground slopes east by south; in the eastern, west by south. In other words, the jointage is quaquaversal in the bottom of a steep-walled ravine or gorge. It must be said that such jointing can hardly be explained by the formation of concentric rift-planes through atmospheric changes of temperature. The conditions seem rather to confirm the more general view that the structure is an original phenomenon due to cooling.

The granite, excepting in a narrow contact zone, remains quite uniform in character throughout the stock. It is a typical pseudoporphyritic alkaline biotite-granite (spec. 2). The color is a light grayish pink, the grain medium to coarse, the structure hypidiomorphic granular in the groundmass. The phenocryst-like constituents are quartz, microperthite, orthoclase, and soda-orthoclase (with a specific gravity of 2.584 at 16° C.), accompanied by a small proportion of biotite individuals. These minerals have the same features as in

[a] Brögger, Zeit für Kryst., Vol. XVI, 1890, p. 193.

the nordmarkites. They compose the groundmass in which a considerable amount of multiple-twinned albite (near Ab_8 An_1) and titanite with some magnetite, zircon, apatite also occur. The phenocrysts are not sharply separated from the groundmass in size, and it is likely that there has been only one generation of those constituents. The biotite is nearly uniaxial. The large amount of FeO in the analysis suggests that it is a lepidomelane. Titanite is beautifully crystallized with the ordinary rhombic outlines and well-developed prismatic cleavage. Its pleochroism is strong:

a, pale yellow.
b, yellow.
c, reddish yellow.
c>**b**>**a**.

Pseudomorphs of magnetite (ilmenite?) after titanite are not uncommon. In one out of seven slides made from this rock a single small individual of pale-green amphibole was discovered. Augite fails entirely. Here, as in the other stock rocks of the area, the quartz is rich in liquid and gaseous inclusions and in negative crystals arranged in lines and also provided with double bubbles of gas immersed in liquid.

The order of crystallization is the normal one:

1. Titanite, apatite, zircon, and magnetite.
2. Lepidomelane.
3. Albite and orthoclase.
4. Microperthite.
5. Quartz.

The essential oxides (see Table X, col. 1, p. 84) and their molecular proportions are noted in the following table:

	Analysis.	Molecular proportions.
SiO_2	71.90	1.1980
Al_2O_3	14.12	0.1382
Fe_2O_3	1.20	0.0070
FeO	0.86	0.0120
MgO	0.33	0.0082
CaO	1.13	0.0201
Na_2O	4.52	0.0723
K_2O	4.81	0.0511
TiO_2	0.35	0.0043
ZrO_2	0.04	0.0003
P_2O_5	0.11	0.0008

If all the TiO_2 be ascribed to titanite, and if we assume that the mica contains 10 per cent MgO, 8 per cent K_2O, and 40 per cent SiO_2,

the analysis may be calculated and the quantitative mineralogical composition determined, with small degree of error, as follows:

	Per cent.
Albite molecule	37.9
Orthoclase molecule	27.0
Quartz	25.0
Anorthite molecule	3.9
Biotite	3.3
Magnetite	1.6
Titanite	0.9
Apatite	0.3
Zircon	0.1
	100.0

Chemically, this rock is an ideal equivalent, among the alkaline rocks, of granite among the nonalkaline eruptives, a biotite-granite characterized by a high total of alkalies with the soda and potash in nearly equal proportion. Iron, lime, and magnesia are all low. It is again to the Christiania region that we must go for the already described type nearest to this one. The "granitite" of Lier affords an analysis which is noted in column 4, Table X. In the Norwegian field, as at Ascutney, the biotite-granite is the youngest eruptive excepting the lamprophyres. A close and interesting correspondence between these two rocks is further illustrated in the character of the endomorphic contact phase. It is notably granophyric and miarolitic in the Norwegian occurrence, and, as we shall see, is in these respects similar to the Ascutney rock.

BASIC SEGREGATIONS IN THE GRANITE.

The homogeneity of the biotite-granite is affected by the presence of nodular basic segregations which, while not nearly so abundant as in the nordmarkites, are characteristic of the rock. They vary in color, composition, and size. Three classes may be distinguished, not only from each other, but, as well, from the metamorphosed schist inclusions, which occasionally appear within the mass of the stock.

The commonest segregation is of a more basic character than the other two kinds (spec. 1a). It is dark greenish gray in color, spherical, oval, or lenticular in form, and in the hand specimen sharply outlined against its host. In thin section, however, it is once more seen that this macroscopically sharp outline of a segregation does not forbid a very intimate interlocking of its minerals with those of the host. The size may vary from that of a pea to nodules as large as a man's fist. Under the microscope the nodule is seen to be a panallotriomorphic aggregate of much biotite, hornblende, and triclinic feldspar always close to and averaging the oligoclase, Ab_3An_1, together with smaller amounts of microperthite and orthoclase. Interstitial quartz, much titanite and apatite, and a remarkably small amount of

magnetite comprise the accessories. The hornblende is not identical with that of the syenite nodules, as is shown by the pleochroism:

a, pale yellowish green.
b, olive-green (medium to strong absorption).
c, olive-green with a strong bluish cast (medium to strong absorption).
b>**c**>**a**.

The other constituents have the same properties as the parent rock. Often in this class of segregation there are small secondary nodules of nearly pure biotite and hornblende, some of which, by the concentration of the mica around the periphery, recall the kernels of the nordmarkites. On the other hand, the general continuity of the main segregation may be interrupted by light-colored spots composed chiefly of oligoclase, quartz, and idiomorphic hornblende.

But one example of the second type of segregation has been found. This is a gray, roundish mass about 7 feet (2.1 meters) in diameter occurring near the 2,100-foot contour close to the northern contact (with the syenite) of the great southwestern tongue of the granite (spec. 113). This large nodule is strongly alkaline, the predominant feldspars being microperthite, albite (pure or charged with the anorthite molecule up to the limit, Ab_8An_1), microcline, and probably cryptoperthite—named in the order of their abundance. Free quartz makes up probably as much as one-third of the rock. A hornblende that has not been observed in any other rock of the area is the remaining essential. It forms long, narrow, microlitic, irregularly terminated blades. It is pleochroic according to the scheme:

a, light greenish yellow.
b, deep brownish green.
c, deep brownish green with a strong bluish tinge.
b=**c**>**a**.

Much idiomorphic titanite, a few rare corroded plates of biotite, many crystals of magnetite, considerable apatite, and very rare zircons form the list of accessories. The structure is here hypidiomorphic granular.

Allied to the second type is a third class of the segregations, type analyses of which are given (Table X, cols. 2 and 3, p. 84). Here the biotite is much more common than the hornblende, the feldspars and accessories remaining the same in nature and relative abundance (spec. 1b). Quartz is not so abundant. The structure is the hypidiomorphic granular. The feldspars are somewhat altered, as is indicated in the chemical analysis. Calcite and a little muscovite are the secondary products. The microscopic diagnosis and the analysis agree in putting these segregations among the alkaline quartz syenites (åkerites). Again, it will be observed that there is an especially large amount of the mineralizer, fluorine, in the segregation.

TABLE X—*Analysis of biotite-granite.*

	1.	2.	3.	4.
SiO_2	71.90	59.27	56.01	75.74
Al_2O_3	14.12	15.76	[a] 15.19	13.71
Fe_2O_3	1.20	2.07	2.34	} 0.55
FeO	0.86	3.57	4.89	
MgO	0.33	3.04	4.67	Trace.
CaO	1.13	3.69	4.85	1.26
Na_2O	4.52	5.63	5.66	3.72
K_2O	4.81	3.33	2.16	4.69
H_2O above 110° C.	0.42	0.74	0.36	} 0.46
H_2O below 110° C.	0.18	0.23	0.90	
CO_2	0.21	0.30	Undet.	....
TiO_2	0.35	1.12	1.13	0.17
ZrO_2	0.04	0.04	....	....
P_2O_5	0.11	0.42	0.53	....
Cl	0.02	0.08	Undet.	....
F	0.06	0.42	Undet.	....
FeS_2	Trace.	0.07	0.09	....
NiO, CoO	....	Trace.	0.03	....
MnO	0.05	0.37	0.40	....
BaO	0.04	Trace?	Trace?	....
SrO	Trace.	Faint tr.	....	....
Li_2O	Trace.	Trace.	....	....
	100.35	100.10	99.21	100.30
O=F, Cl	0.03	0.19	....	....
	100.32	99.91	....	....
Total S	Trace.	0.037	....	....
Sp. gr	2.616	2.661	2.720	....

[a] With ZrO_2.

1. Biotite-granite, Ascutneyville quarries: analysis by Hillebrand.
2. Basic segregation in the biotite-granite: analysis by Hillebrand.
3. Another sample of the last, containing more hornblende: analysis by Hillebrand.
4. "Granitite" from Lier, Christiania region: Brögger, Zeit. für Kryst., Vol. XVI, 1890, p. 72.

ENDOMORPHIC ZONE OF THE GRANITE.

The detection in the field of the actual plane of contact of granite and syenite is rendered comparatively easy on account of a conspicuous structural variation which characterizes the endomorphic zone. At the average distance of 20 feet (6.1 meters) from the con-

tact the normal granite becomes much more porphyritic in appearance (spec. 105). The phenocrysts are chiefly quartz, which may either retain its dimensions in the normal rock or may form much larger doubly terminated crystals. The groundmass is much finer grained, though always holocrystalline, and is either granophyric or identical in general structure with the normal granite. Large terminated crystals of quartz may sometimes be seen projecting from the syenite into the granite in the same way as in the apophyses already described. Especially marked on the ledges of the contact zone are abundant roundish miaroles from 1 inch (2.6 centimeters) to 3 inches (7.8 centimeters) in diameter, either completely filled with crystalline matter or presenting cavities lined with well-formed crystals (spec. 106).

The usual occupants of the miaroles are quartz crystals showing the common terminal and prismatic planes and crystals of the same feldspars as occur in the granite proper. The feldspars are flesh colored or light brownish and, in thin section, turbid. They bear the planes (001) (010) (110) ($\bar{1}$01) ($\bar{2}$01) (021) and ($\bar{1}$11); (010) and (001) are especially well developed. The commonest of these feldspars seems to be a genuine microperthite. It illustrates in excellent fashion the rare Manebacher law of twinning and the murchisonite cleavage. The triclinic feldspar of the intergrowth is pure albite, giving an extinction angle of 19° on (010). Microcline and orthoclase crystals also occur in the miaroles. The latter has the small optical angle of sanidine. Finally, pseudomorphs of limonite after siderite completes the list of the minerals which have been found in the miaroles. Biotite seems to be absent. A close parallel to this endomorphic zone is furnished in the aplitic granophyre described by Brögger as the contact phase of the alkaline biotite-granite of Lier,[a] which in other respects resembles the Ascutney rock.

The endomorphic zone has been enriched by the incorporation of a certain amount of basic material evidently derived from the syenite. In the granophyric groundmass there are sporadic irregular granular areas impregnated with an alkaline hornblende near barkevikite and biotite. These are not found where the granite is in contact with the phyllites.

LAMPROPHYRES.

A number of dikes of lamprophyric habit cut the syenites at various points, and rocks of the same character intersect the Basic stock and the schists. No such dike has been discovered in the granite stock, but it is probable that they are all younger than that stock. They belong either to the class of camptonites or to the class of diabases. A similar association of the two groups in the same region has been described by Kemp as occurring on the Maine coast.[b]

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[a] Zeit. für Kryst., Vol. XVI, 1890, p. 72. [b] Bull. Geol. Soc. Am., Vol. I, 1890, p. 32.

CAMPTONITES.

At the top of Little Ascutney a camptonitic dike cuts the nordmarkite-porphyry dike, the paisanite dike, a horse of the breccia, and the diorite. The rock is a very compact grayish-black mass, in which here and there a hornblende crystal and, more rarely, a feldspar appear as phenocrysts (spec. 57). In thin section it is seen to be an acid camptonite of the usual structure and composition. The hornblende phenocrysts are idiomorphic and measure from 1 to 3 millimeters in length. The pleochroism and absorption are those of a common basaltic hornblende:

a, pale brownish yellow.
b, deep, rich brown.
c, deep, rich brown.
$\mathbf{c} \gg \mathbf{b} > \mathbf{a}$

The extinction on (010) is about 15° 30′.

The plagioclase is apparently very uniform in composition and averages the basic labradorite, Ab_2An_3, both in the rare phenocrysts and in the groundmass.

The rock is greatly altered, and this characteristic adheres to all the camptonites of the area. Chlorite, epidote, calcite, secondary quartz, and kaolin are the products of decomposition.

Analysis 1, in Table XI, represents the approximate composition of the average camptonite of the area (spec. 74). It was made from a type differing from that just described in containing a small proportion of augite in the groundmass and, more rarely, among the phenocrysts. The feldspar is here again the labradorite Ab_2An_3. The augite is much altered (into uralitic amphibole, chlorite, and the ores) from its original diopsidic condition. Dikes corresponding to this analysis were found cutting the syenite on the Windsor trail about 500 yards (457 meters) from the main summit of Ascutney Mountain, cutting coarse diorite in the saddle at the east end of Little Ascutney, and cutting gneiss east of the notch road and southwest of Brownsville.

While there is a noteworthy difference between this analysis and that of Hawes's classic camptonite, the former agrees well with the average analysis of camptonite as calculated by Brögger (cf. Table XI.)

TABLE XI.—*Analysis of camptonite.*

	1.	2.	3.
SiO_2	48.22	41.94	43.65
Al_2O_3	14.27	15.36	16.29
Fe_2O_3	2.46	3.27	
FeO	9.00	9.89	14.76
MgO	6.24	5.01	5.96
CaO	8.45	9.47	10.16
Na_2O	2.90	5.15	3.05
K_2O	1.93	0.19	1.50
H_2O above 110° C	1.66	3.29	
H_2O below 110° C	0.28		
CO_2	0.15	2.47	
TiO_2	2.79	4.15	4.63
ZrO_2	0.03		
P_2O_5	0.64		
Cl	0.10		
F	0.05		
FeS_2	0.36		
NiO, CoO	0.03		
MnO	0.20	0.25	
BaO	0.04		
SrO	Trace.		
Li_2O	Trace.		
CuO	Trace.		
	99.80	100.44	100.00
O=F, Cl	0.04		
	99.76		
Total S	0.19		
Sp. gr	2.810-2.869		

1. Camptonite dike, Ascutney Mountain; analysis by Hillebrand.
2. Classic camptonite, Campton Falls, N. H.; Rosenbusch: Elem. der Gesteinslehre, 2d ed., 1901, p. 244.
3. Average analysis of eight camptonite dikes; Brögger: Quart. Jour. Geol. Soc., Vol. L, 1894, p. 26.

The hornblende has not been analyzed; it is, hence, not possible to calculate the analysis. The specific gravity of these dikes varies from 2.810 to 2.869; on account of alteration, no two pieces, even from the same hand specimen, will agree in specific gravity.

DIABASE DIKES.

The second class of melanocratic dikes comprises compact, equigranular or porphyritic diabases of normal composition and structure,

thus not differing essentially from the common dikes of the same rock occurring so abundantly up and down the Connecticut Valley (spec. 120). The feldspar is here also near the basic labradorite Ab_2An_3. Like the pale-green intersertal augite, it is much affected by weathering; the products of the change are the same as in the camptonites. A sulphide, probably pyrite, is visible in notable amount, even in the hand specimen. The magnetite is strongly titaniferous. Zircon and titanite are absent, and there is comparatively little apatite. The specific gravity was measured at 2.922. The total analysis is given in Table XII. It corresponds to that of a common, somewhat weathered diabase.

TABLE XII.—*Analysis of diabase (by Hillebrand)*

SiO_2	49.63
Al_2O_3	14.40
Fe_2O_3	2.85
FeO	8.06
MgO	7.25
CaO	9.28
Na_2O	2.47
K_2O	0.70
H_2O above 110° C	1.47
H_2O below 110° C	0.27
CO_2	1.36
TiO_2	1.68
ZrO_2	Trace?
P_2O_5	0.25
Cl	0.07
F	Trace
FeS_2	0.22
NiO, CoO	0.04
MnO	0.17
BaO	Trace?
SrO	Trace?
Li_2O	Trace
	100.17
O=F, Cl	0.02
	100.15
Total S	0.12
Sp. gr	2.922

SUMMARY.

The list of eruptive rocks in Mount Ascutney includes the Basic stock of gabbros and diorites transitional into one another and into an acid essexitic phase, ramifying dikes of younger diorite, dikes of a rock type not heretofore described and called "windsorite" from this Ascutney occurrence, the nordmarkite-porphyry dike-like stock of Little Ascutney, the pulaskite stock of Pierson Peak, the great paisanite dike of Little Ascutney, the variable nordmarkites of the Main syenite stock with granitic and monzonitic phases, the homogeneous alkaline biotite granite of the Ascutneyville stock, and the

aplites and lamprophyres (diabase and camptonites) cutting nearly all the other bodies.

Chemically, the series of eruptives as a whole is characterized by normal silica, high alkalies, the potash slightly predominating, normal alumina, medium iron, low magnesia, low lime, and high titanic oxide. Mineralogically, they are rich in feldspar which is generally microperthitic, and are poor in biotite and bisilicates. Especially noteworthy is the extraordinary development of indigenous basic nodules of segregations and of "schlieren" in the different rock bodies, including both dikes and stocks. The abnormal abundance of the segregations is probably to be connected with the smallness of the conduit through which each irruption took place. Variations of temperature, abundance of foreign fragments, and the repetition of intrusion in the same conduit have all played their part in disturbing the normal process of crystallization.

Considering the small area occupied by the Ascutney intrusives, they must be considered as having an unusually wide range of composition (see list on p. 36). While dioritic types fail in the allied petrographical province of the Christiania region and nordmarkites and related alkaline rocks are absent in the Monzoni region, both of these classes are represented at Ascutney. The intimate association of independent bodies of such nonalkaline rocks as the gabbros and diorites of the oldest stock and of the older basic dikes, with the several bodies of typical alkaline syenites and granite, is to be particularly emphasized. That such an association is not rare, in America at least, is shown by its repeated occurrence in New York State[a] and in Essex County, Mass.[b] Not the least significant fact concerning the Ascutney eruptive group is the occurrence of rock types transitional between the nonalkaline and alkaline irruptives. Thus there is not only the most striking consanguinity among the respective members of each of these classes, but the two classes are themselves allied by a family relationship which is reflected also in many details of mineralogical and chemical composition.

Among the details described in connection with the irruptives, we may recall some which, while of greater or less importance to the general geology or mineralogy of the area, are not implied in the foregoing résumé of the intrusions. These include the evidence for the cylindrical character of the main controlling stock of Mount Ascutney itself, the remarkable tarnishing which slight exposure produces in the nordmarkite of the Windsor quarry and in the related paisanite of Little Ascutney, the great masses of breccia in the nordmarkite porphyry and paisanite dikes, and the interesting endomorphic phases, especially of the biotite-granite. Finally, the considerations relative to the mode in which the conduit has become occupied by the different intrusives will be summarized in the following chapter.

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[a] Cushing, Bull. Geol. Soc. Am., Vol X, 1899, p. 177. Smyth, Ibid., Vol. VI, 1895 p. 263. Eakle, Am. Geol., Vol. XII, 1893, p. 35.

[b] Washington, Jour. Geol., Vol. VI, 1898 p. 799

CHAPTER V.

THEORETICAL CONCLUSIONS.

MANNER OF INTRUSION OF THE STOCKS.

Probably the most important question in connection with the dynamical geology of the mountain centers about the actual method of injection followed by each of the five largest eruptive bodies.

Hitherto it has been assumed that the Ascutney rocks belong to the category of genuine intrusives and that, for example, we have not here to do with a deeply eroded volcanic neck or pipe. This view will be still held in the further discussion of the rock bodies. The evidence, however, that the granitic rocks now exposed do not, after all, represent the deep-seated equivalents of magmas which, in the eruptive periods, escaped at the earth's surface as lava flows, is largely but negative. To exclude this volcanic hypothesis it is clearly not sufficient that the igneous bodies have all the characteristics of a plutonic origin and that there is in the vicinity, at present, lack of explosion breccias or lavas in any form. The complete removal of such products is only a question of the time allowed and the depth of denudation since the early period of the eruptions. Nor, again, and just as surely, is the general lack of flow structure showing a relatively rapid upward movement of the magma of distinct help in deciding the alternative.

The peculiar arrangement and form of the stocks, especially the lobate plan of the granite, seem to give greater satisfaction in the plutonic hypothesis. But a much stronger reason, affording cumulative evidence for its adoption, is doubtless to be found in the analogy of Ascutney Mountain with a score of other granitic areas in Vermont alone. There appears to be no evidence at all for the volcanic nature of these igneous bodies. Although the geological conditions are often, particularly in the smaller areas, very similar to those at Ascutney, extrusive rocks seem never to be organically associated with a single granitic mass. So far as known, there is no more reason to attribute a volcanic origin to any one of these smaller granitic bodies in Vermont than to the others; nor, indeed, than to the great massifs typified by the Barre granite. The transition in size from the smallest to the largest area is gradual, and mere size and shape will not suffice as a criterion of volcanic origin for any one. It is, perhaps, not too much to say that, if the Ascutney bodies occupy the vent of an ancient greatly eroded volcanic neck, the Barre granite itself, contrary to the

received opinion of geologists, may be regarded as possibly of the same origin. In other words, it is reasonable to believe that the volcanic hypothesis for Ascutney Mountain has no stronger foundation in fact than it has for normal granitic areas the world over. In this view, the igneous rocks of Ascutney are all irruptive and each irruptive body assumed its present position and full volume only after some process had prepared the corresponding space within the country rock[a]. The problem before us relates to the manner in which that preparation was carried out.

APPLICATION OF EXISTING THEORIES TO THE ASCUTNEY INTRUSIONS.

It is held by some of our ablest masters in petrological science—perhaps by most of them—that stocks, sills, laccoliths, and dikes are, from the point of view of dynamical geology, of the same nature—i. e., that they vary only in size and form. Each is composed of a consolidated rock magma which has been injected into the country rock because of a previous or accompanying opening of cavities within the earth's crust. Displacements of folded and faulted rocks in mountain massifs are made responsible for the cavities or chambers. The latter may be supposed to antedate the eruption (plainly an inadmissible premise for the larger eruptive bodies) or to have been magmatically filled pari passu with the dislocation. In either case the adherents of this theory believe that no important assimilation of the country rock by the invading magma takes place, and that, therefore, the composition of the magma is not affected by such assimilation.

It is clear from the foregoing discussion of the Ascutney intrusives, as well as from the inspection of the map (Pl. VII), that none of the larger ones is laccolithic in character. The syenite-porphyry of Little Ascutney has apparently followed a zone of weakness, the contact of the gneiss and Basic stock. Though for this reason dike-like in its geological relations, it has so far enlarged its conduit as to assume the proportions of a stock. The other four bodies are true stocks. Each eruptive cuts across the schists, so that the igneous contact generally stands at a high angle to the strike of the schists. Only at the eastern end of the mountain are the two parallel, and it has already been noted that the surface of contact of the Main syenite stands nearly vertical, and is thus not coincident with the dip plane of the schists there any more than on the other slopes of the mountain. The facts show that a laccolithic origin can not be hypothecated for the Main syenite, much less for the granite.

The east-west elongation of the igneous area as a whole might suggest that the intrusions occupy a zone of dip faulting in the schists. But the transitional contact belt of the phyllitic and gneissic series is easily recognized on both the north and the south side of the moun-

[a] The term "country rock" is used in this report as a convenient expression denoting the terrane invaded by and thus in contact with an irruptive body.

tain, and it is quite as easily seen in the field that the belt has not been appreciably offset by a fault transverse to the strike. It is likewise in the highest degree improbable that displacements parallel to the strike of the schists can be safely called upon to explain the spaces now filled with the solidified magmas.

The facts derived from field study also speak strongly against the idea that all or any of these intrusions took place in consequence of the removal of the country rock en bloc by faulting. It might be conceived that faulting could have led to the transfer of the displaced schists upward, as if punched out by a huge die,[a] or to the foundering of the corresponding blocks, which would thus become buried deeply by the magma entering the resulting chamber. If such circling faults had occurred we should expect some evidence of them to be yet decipherable in the country rocks. Yet the latter show no sign of disturbance that can be traced to those particular movements. Even if the intrusion had taken place after this manner in one instance, it is in the highest degree improbable that so unusual a dynamic process should have been repeated three times in this limited area. The ground plan of the different stocks as expressed in the geological map can scarcely be explained on the hypothesis of circling faults. We must rather conclude, from a survey of the ground, that each of the stock bodies has actively displaced its country rock so as to find room for itself. The Basic stock has displaced the gneisses; the nordmarkite stock has displaced diorites and schists; the stock of Pierson Peak has displaced gabbros and diorites; the nordmarkite-porphyry of Little Ascutney has displaced gneisses and diorites, and the granite has displaced the syenite and a small amount of the phyllites.

A second commonly held view of many stocks and of many "batholiths" is that they have undergone their "mise en place" as a result chiefly of the caustic and assimilating property of the igneous magma in contact with the country rock. Thus, while Brögger regards the Predazzo-Monzoni area as illustrating in a thoroughgoing manner the process of differentiation in deep-seated chambers prepared by crustal movements, Fouqué finds in the same province an almost typical example of assimilation. It is here, as elsewhere, a question of the degree to which the process produces its effect, as every field geologist is bound to credit the assimilation of small foreign fragments caught in a molten magma and, as well, the local and subordinate digestion of the walls at certain of the eruptive contacts already described in geologic literature.

Stated in its usual form, the assimilation hypothesis also will hardly fit the facts recorded for the Ascutney eruptives. The oldest stock is quite basic, though it cuts a series of acid gneisses. The Main syenite shows no basification at its contact with the diorites. Its endomorphic contact phase is, on the contrary, there, as elsewhere, more strongly quartzose and has often even a smaller proportion of bisilicate than

[a] Recalling the "bysmalith" of Iddings, Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II, 1899, p. 16.

the average syenite. The biotite-granite has, it is true, a hornblende among the constituents of its basic segregations; but the endomorphic zone, where the granite comes in contact with the older syenite, does not exhibit any special sympathy with that rock. Still more important is the complete lack of basification in the pulaskite of Pierson Peak which cuts the diorite and associated gabbro. That stock is of small dimensions. It is alkaline, and hence is composed of material which in its magmatic form must have been of specially caustic nature. The crystalline rock through which the magma found its way has a markedly different composition. There, if anywhere, we should, on the assimilation hypothesis, look for an endomorphic zone sensibly affected by the country rock. The failure of such a zone is as unquestionable as in the notable case of the shonkinite laccolith of Square Butte, Montana.[a] The Pierson Peak stock is made up of a homogeneous syenite which is indistinguishable, save for the absence of free quartz and the disappearance of much of the essential bisilicate, from an abundant phase of the Main stock of Ascutney Mountain proper. Both stocks are syngenetic with the stock-like dike of Little Ascutney. The occurrence of all three with essentially similar mineralogical and chemical properties, but with essentially diverse country rocks, seems to prove that they came from a single magma which persisted in nearly its pure form even after injection and notwithstanding the well-known solvent power of alkaline magma on both acid and iron-rich basic rocks.

SUGGESTED HYPOTHESIS OF THE MANNER OF INTRUSION.

Without considering other and less important views of the mechanics of intrusion, which, suggestive as they are, must yet be regarded as insufficiently supported by observations in nature, a somewhat detailed statement may be made of a third hypothesis which has forced itself upon the writer. It not only explains the facts as far as Mount Ascutney is concerned, but meets as well all the tests which have yet been applied to it from the results of experimental geology, from observations in other regions, and from the theory of igneous bodies generally.

Most geologists are agreed that intrusion on a large scale is not a sudden act, but occupies a period of time comparable to that required for complex folding in a mountain massif. This conclusion has been reached by those advocating the assimilation theory, as well as by those holding the rival theory of laccolithic and allied crustal displacement.[b] While the conclusion of any investigator as to the time required for a magmatic injection is itself in part a by-product of the intrusion theory ruling in his mind, it is yet noteworthy that the present exponents of the opposed theories accord in ascribing great duration to the time required for granitic intrusions at least. It will,

[a] Weed and Pirsson, Bull. Geol. Soc. Am., Vol. VI, 1895, p. 389.

[b] W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 149.

then, be no antecedent objection to the hypothesis now to be proposed that it is based on a process of integration of small effects, and that the integration suffices for the geological work in hand only after the lapse of a long period between the beginning and end of the process.

The starting point of the hypothesis is found in the consideration of the phenomena of the contact belt belonging to each irruptive body. The present assimilation theory of Michel Lévy and others demands a study of the same belt as a test, rather than as the basis of formulation.

At many points in the internal contact zone of any one of the stocks numerous fragments of the country rock may be seen in the eruptive (Pl. VI). These are completely isolated, immersed in the crystallized magma, though often they are seen to have moved only a few feet or inches from the parent rock. As found in endomorphic zones of plutonics generally, the fragments are further quite normal in showing angular outlines and very sharp boundaries against the eruptive rock. There is usually, indeed, plain indication that these fragments have suffered little, if any, chemical solution by the magma. Recent experiments, however, have established beyond peradventure that, at temperatures but slightly above that of complete fusion of any silicate mixture, every important rock-forming mineral may be completely dissolved in that magma.[a] The conclusion seems unavoidable that, at the moment when a given foreign fragment was torn or floated off from its wall and thereafter, the immersing magma was relatively cool, and thus enfeebled in its solvent power. That its metamorphosing power was likewise diminished is suggested by the fact, borne out by microscopic study, that the recrystallization of the fragment is generally no more advanced than that of the country rock many feet from the irruptive.

But a still stronger proof of a comparatively low temperature at the moment of isolation of any one of the fragments is the fact that it is now to be seen floating, as it were, or, to be more accurate, suspended, in the magma. A brief consideration of certain experimental determinations shows that such suspension can occur in a normal magma invading rocks of average specific gravity only on the condition that the magma is highly viscous and near the point of consolidation. It has been established that, for each class of holocrystalline silicate rocks, the specific gravity of the corresponding glass is considerably lower than that of the natural rock, and that the specific gravity of the same rock when completely melted is still lower than that of the glass. No investigation has been made on these points for any of the Ascutney rocks, but it is fair to use the results for similar rocks from other parts of the world.

The most important case for consideration is evidently the relation

[a] Among other papers, cf. C. Doelter, Die Schmelzbarkeit der Mineralien und ihre Löslichkeit in Magmen. Tscher. Min. u. Petrog. Mitth., Vol. XX, 1901, p. 307; and Ueber einige petrogenetische Fragen: Centralbl. f. Min., Geol. und Pal., 1902, p. 545.

between the specific gravity of the rocks in the Gneissic series and that of the diorite-gabbro magma; therein we must have the closest approximation in density between the material of any one stock and its staple inclusion. The specific gravity of the chemically analyzed diorite is 2.936. Similar determinations were made for the more basic gabbro phases collected at three different parts of the same stock; the values here ran from 2.95 to 3.19. The average for the gabbro is 3.08. We may take 3.10 as the approximate average specific gravity of the more basic parts of the oldest stock.

The most thorough and careful experiment bearing on this question is that made by Barus in the fusion of diabase.[a] He found that a sample of diabase at 20° C. had a specific gravity of 3.0178 and the glass produced by the dry fusion of the same rock had, at the same temperature, a specific gravity of 2.717. The density was much less in the molten state. Thus, at 1,400° C. the specific gravity was only 2.523, corresponding to an increase of volume of about 20 per cent. A critical discussion of many fusion experiments by Delesse and Cossa along the same line shows a close agreement in the behavior of the basic rocks treated in the older researches, as compared with that of the diabase of Barus's refined experiment.[b] One phase of the correspondence is shown in the following table:

Rock type.	1. Sp. gr. of rock at ca 20° C.	2. Sp. gr. of glass at ca 20° C.	3. Net decrease in density, rock to glass.	4. Net increase in volume, rock to glass.	5. Sp. gr. of rock molten at 1,400° C., calculated from Barus's fusion curve.
			Per cent.	*Per cent.*	
Diabase of Barus	3.0178	2.717	10.00	11.2	2.523
Average gabbro of Delesse	2.999	2.652	11.57	13.1	2.507
Average diorite of Delesse	2.859	2.657	7.07	7.6	2.390
Quartz-diorite of Cossa	2.667	2.403	9.90	11.1	2.229
Syenite of Cossa	2.710	2.430	10.33	11.5	2.266
Average granite of Delesse	2.684	2.438	9.16	10.0	2.243
Average of above			9.67	10.7	
Gneiss of Delesse	2.821	2.625	6.95	7,5	2.358

It is seen that these various independent investigations establish a tolerably constant ratio for the relative volumes of a holocrystalline, plutonic rock and of the glass produced by its fusion. Of special interest are the small differences among the results of Barus, Delesse, and Cossa on diabase, gabbro, and quartz-diorite. These are rocks related to various facies of the Basic stock at Ascutney Mountain.

[a] Philos. Mag., Ser V, Vol. XXXV, 1893, p. 173; and Bull. U. S Geol. Survey No. 103, 1893. Cf. Joly, on fusion of basalt, Trans Roy. Dublin Soc., Ser. II, Vol. VI, 1897, p 298

[b] Delesse, Bull. Soc. Géol France, Ser. II, Vol. IV, 1847, p. 1380; Cossa, ref. by Zirkel, Lehrbuch der Petrographie, Vol. I, 1893, p 681

The behavior of all basic rocks under fusion has, unfortunately, not been tested for high temperatures, but, for reasons well established by Barus and derivable from a survey of this particular field of research, it is admissible to apply the fusion-curve of Barus to any rock of allied composition. On this supposition, at one atmosphere of pressure, the specific gravity of the Ascutney gabbro would fall from 3.10 to 2.59 at 1,400° C. and that of the average diorite from 2.94 to 2.46. At this temperature the rock would remain highly fluid even at the depth of 5 miles in the earth's crust. The specific gravity of the normal gneisses occurring near the Basic stock ranges from about 2.69 to about 2.76, with a probable average of 2.73.

To determine what these would be if fragments with the corresponding densities could be kept solid and obey the law of expansion for solid rock, at 1,400° C., it is permissible to use Reade's expansion coefficient for granite without incurring serious errror.[a]

Barus has shown that pressure simply elevates the melting point in the normal type of fusion without interfering essentially with the value of the coefficient determined at ordinary temperatures and pressures.[b] The average gneiss would have, as a result of the application, a calculated specific gravity of 2.63. It must be remembered, too, that contact metamorphism here, as generally elsewhere, would raise this value still higher, and that any acidification of the magma in contact with the gneiss would lower the density of the magma. Now, the beautiful experiments of Barus in the fusion of various carbon compounds under varying pressures show that, in thermal expansibility and in compressibility, they behave in a manner extremely similar to the few silicates on which any studies in fusion have been made. He has shown that naphthalene, a substance obeying, like diabase, the normal law of fusion, is slightly more compressible as a liquid than as a solid.[c] The fusion curves indicate that, for the same increase of pressure, liquid naphthalene gains in specific gravity about twice as fast as solid naphthalene. The compressibility of a fused silicate rock is probably, then, approximately twice that of the same rock when solid. But his diabase curve demonstrates that the thermal expansibility of the liquid rock is 1.9 as rapid as that of the solid rock. Thus a block of cold solid gabbro immersed in a deep-seated molten magma of the same chemical composition would be less condensed by the pressure than the molten rock, but the effect on relative densities would be partly compensated by the relative rate of expansion due to any superheating of the magma. A block of gneiss would behave in a manner closely similar to that of a block of gabbro. It is believed that the pressure of several thousand atmospheres would not affect seriously the contrast in densities which experiment would lead us to expect if a fragment of the Ascutney gneiss were completely immersed in the fused gabbro at plutonic pressures. If this be true, only one

[a] Origin of Mountain Ranges, London, 1886, p. 110. [b] Philos. Mag., Vol. XXXV, 1893, p. 306.
[c] Am. Jour. Sci., 3d ser., Vol. XLII, 1891, p. 140.

conclusion can be drawn. Since uniform pressure affected both gneissic fragment and magma when the former was parted from the parent country rock, the difference of density of the two would prevent the suspension of the fragment as a mere matter of flotation. Further, the fragments, like the basic segregations, could remain in the positions in which they may now be seen only if the magma possessed a high viscosity at the time when they were rifted off.

If we are forced to this view of the conditions in the Basic stock, still more surely may we have confidence in it as explaining the presence of even more numerous schist fragments in the syenitic and granitic stocks. The following table shows that, even in the holocrystalline state, each irruptive rock has a specific gravity lower than its country rocks. It indicates further that the inequality increases in the same sense the greater the degree of exomorphic change in the invaded schist.

Eruptive rock.	Specific gravity.	Corresponding country rocks.	Approximate specific gravity.
Main stock	2.616 - 2.683, average, 2.65	Normal sericitic schist	2.70
		Average of three specimens from phyllite of contact zone.	2.84
		Average of Basic stock	3.05
Nordmarkite-porphyry of Little Ascutney.	2.633	Average of Basic stock	3.05
		Average of gneisses	2.73
Pulaskite, Pierson Peak	about 2.63	Average of Basic stock	3.05
Granite stock	2.616	Normal sericitic schist	2.68
		Average of hornfels from phyllitic contact.	2.84
		Average of Main syenite	2.65

Delesse found that, in melting down granite to a glass, the specific gravity was lowered about 10 per cent on the average.[a] Accepting his figure, the biotite-granite of Ascutney would afford a glass with a specific gravity of about 2.35.[b] A block containing 1,000 cubic feet of the porphyritic phase of the Main syenite would tend to sink in a magma of the latter specific gravity by virtue of a downward pull equal to the weight of at least 5.3 tons of rock in the air, and evidently, from Barus's results, still faster in the thinly fluid granite itself. It is in the highest degree probable that this difference of density would not be significantly altered by the great pressures reigning at the moment when such a block would become detached from the wall of the granite body. Nothing less, then, than a very unyielding, highly viscous

[a] Annales des Mines, Ser. II, Vol. IV, 1847, p. 1380.
[b] Cf. granite, specific gravity 2.63; obsidian, 2.3 to 2.4.

condition of any one of the Ascutney magmas can account for the presence of the foreign blocks in the immediate vicinity of their homes in the invaded formations. The viscosity probably approached that of the Archean granitic magmas, which, according to Lawson, were capable, under enormous dynamic stresses, of shearing and attenuating foreign blocks suspended in those magmas near the moment of consolidation of the latter. Lawson has also suggested that, although the viscosity was so great, the temperatures may have been high enough to melt up the more basic foreign fragments completely.[a] Whether solid or molten when sheared or pulled out, such blocks could not sink in the magma, because of its thick, pasty condition.

At Ascutney Mountain, as elsewhere, the magmas that formed the stocks were capable of forcing their way through fissures a few inches or but a fraction of an inch in width, for distances of hundreds of feet or yards from the respective main eruptive mass. These are clearly offshoots from the stocks, though the junction with the latter may not be seen in many instances. Each magma must have been very fluid when it filled its own set of these narrow fissures.[b] That conclusion accords with the results of the recent careful experiments of Doelter.[c] He has shown that there are but comparatively small differences among the temperatures at which a granitic rock or an artificial mixture of silicates is softened by heat, becomes thinly molten, or solidifies from that molten condition. Thus he found that a foyaitic mixture (of orthoclase, elæolite, and ægirine) became soft at 1,070° C., thinly fluid at 1,110–1,115°, and then solidified at 980–1,000° C. The corresponding figures for a basaltic mixture (of labradorite, augite, olivine, and magnetite) are 1,120–1,125°, 1,140–1,150°, and 980–1,000° C. Predazzo granite and Remagen basalt became softened at respective temperatures of 1,150° and 992° C.; completely molten at, respectively, 1,240° and 1,060° C. But a slight restoration of heat, therefore, would be necessary to reconvert a cooled and toughly viscous endomorphic zone, yet hot enough to quarry blocks from the invaded formation, into a highly mobile state. It can not be denied that there must occur a loss of at least that small amount of heat in the closing stage of stock intrusion. The magnitude of plutonic pressures puts no difficulty in the way of accepting this conclusion as to high fluidity. Oetling has proved, on the contrary, that the temperature point of consolidation of melted rocks and silicate mixtures is lowered by pressure. He, in fact, shares the view of Amagat, that, if the pressure be sufficiently high, solidification can not occur at all.[d] Moreover, it

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[a] Geol. Rainy Lake Region, Ann. Rept. Geol. and Nat. Hist. Survey Canada, 1887, Part F, pp. 131-2-3-8, etc.

[b] There is no contradiction between this statement and the previous one of high viscosity in the main magma which isolated and suspended foreign blocks. As implied in a following paragraph, it would simply mean that the apophysal tongues were injected before the magma had come in contact with the present walls of its main chamber.

[c] Tscher. Min. u. Petrog. Mitth., Vol. XX, 1901, pp. 232 and 307

[d] Ibid., Vol. XVII, 1897, p. 370.

is coming to be generally accepted that pressure induces mobility in plutonic magmas by retaining water and mineralizers.[a]

In summary, then: Field observation and experiment agree in attributing a thinly fluid condition, except at the moment of final crystallization, to such magmas as those from which the Ascutney stocks were derived.[b]

High fluidity must have two important results: First, it would facilitate the formation of apophysal tongues, often intersecting; secondly, it would entail a downward strain on any disjointed blocks in the roof contact of the stock body. Following joints, planes of stratification, schistosity, or slipping, the apophyses must seriously impair the strength of the roof and walls. The same planes of weakness, even without the aid of the irruptive wedge, already form a menace to the integrity of the walls and roof, especially the latter; this on account of the gravity component already demonstrated as a result of a difference of density between the solid rock and the magma beneath. Moreover, a shattering of the country rock may be expected by reason of the differential temperature strains induced by the magma.

When, from these causes, a block becomes dislodged and completely immersed in magma, it must sink, and sink rapidly.[c] The space formerly occupied by the block is now filled with magma. In the same manner an indefinite number of blocks may be removed by this natural stoping. New surfaces will continually be presented to the invading magma, and so long as the stated conditions persist there will be greater and greater destruction of the country rock. It is simply a question of time whether the advance of the magma shall be so great as to fashion the chamber of an Ascutney stock or of a great batholith.

A brief statement of this central idea of the stoping hypothesis has been given by Lawson in a review of certain of Brögger's writings. So far as known to the present writer this noteworthy paragraph contains the only clear enunciation of the doctrine to be found in geological literature, and is worthy of quotation in full:

The essential features of the assimilation hypothesis were formulated by the reviewers some years ago, before the publication of Michel Lévy's views, and urged as a satisfactory explanation of the remarkable relations which obtain between the Laurentian granites and gneisses and the upper Archean or Ontarian metamorphic rocks. These intrusive granites and gneisses occupy vast tracts of the Canadian Archean plateau, and there seems to be no escape from the view that they bear a batholitic relation to the crust which they invaded from below. Portions of the crust were absorbed, but there are two possibilities as to the method of absorption, viz: 1, by fusion; 2, by sinking into the magma. The numerous blocks of rock scattered through the granites lend much probability

[a] Doelter, Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 218.

[b] See the general statement by Brögger, Die Eruptivgesteine des Kristianiagebietes, Vol. III, p. 338.

[c] Johnston-Lavis has seen a piece of compact lava sink quickly in a flowing lava stream from Vesuvius. Proc. Quart. Jour. Geol. Soc., Vol. XXXVIII, 1882, p. 240.

to the latter having played a part in the process. Such batholites were doubtless accompanied by laccolitic satellites.[a]

The hypothesis of natural overhead "stoping" accords with the facts known with regard to other kinds of igneous intrusion. Even in the case of those great granitic massifs organically associated with master lines or zones of dislocation (e. g., the tonalite and the "Judicarienlinie" of the Tyrol), the magma chamber may have been largely opened by overhead stoping. The same process may similarly greatly enlarge the deep-seated cross section of a volcanic neck. Yet no one can deny its practical insignificance in the intrusion of sheets or dikes, nor, for obvious reasons, does that fact injure the strength of the proposed hypothesis when dealing with vastly larger igneous bodies. The latter must be much longer molten by reason of their size, and have more direct communication, through convection and other currents, with the earth's interior. The same remark applies in general to laccoliths, although it is possible that, in limited degree, laccolithic magmas may carry on independent stoping, and therewith assimilation, in their hot interiors.

The hypothesis, it will be observed, is allied in one respect to the assimilation theory of Kjerulf, Michel Lévy, Lacroix, and others. According to each of the two views, the plutonic chamber occupied by stock or batholith has been formed by the activity of the magma itself along the internal contact. But, in the older theory, the assimilation at the contact is essentially caustic and chemical; in the newer view the assimilation there is essentially mechanical. The former attempts to explain in one step the opening of the space now filled with eruptive material and the disappearance of the corresponding mass of country rock; the latter has still to give account of the multitude of larger or smaller blocks sunken in the magma. What becomes of them? How far will they sink? What is their fate when they come to rest?

ABYSSAL ASSIMILATION.

It is at once evident that such questions are most difficult to answer in detail; perhaps the second is always destined to remain unanswered. It is evident, too, that we are now many removes nearer the realm of speculation than in any previous explanatory step. Yet it can not be considered a fatal objection to any theory of intrusion that it must refer ultimately to the unexplored interior of the earth. The attempts to solve the plutonic problem with attention rigidly kept on the accessible part of the earth's crust must have but partial success. If experiment, analogy, and the considerations of cosmical physics can aid in explanation, they should be employed. The field geologist has only the earth's outer skin to study; yet granite, with all its relatives, is a product of physiological processes occurring, as it were, in the vital organs of the earth.

The cardinal fact of fluidity in plutonic magmas needs to be viewed

[a] Science, new series, Vol. III., 1896, p. 637.

in relation to the equally certain fact of the earth's rigidity and to the necessity of finding some mechanical explanation for the support of the roof over the igneous body during intrusion. A complete discussion of the former topic would carry us farther afield than the scope of the present report warrants. Suffice it here to note that the same problem confronts every modern theory of intrusion.

In the case of the Ascutney stocks it is believed that the strength of the roof over each irruptive mass was doubtless sufficient to prevent its foundering en masse in the less dense magma. Other and larger stocks and batholiths must be studied in this regard each by itself. As the underpinning of the schist cover of the Ascutney igneous area as a whole was demonstrably aided by a progressive consolidation of the partial magmas, so it is conceivable that there may be a lateral progression of solidification in the homogeneous magma of a much larger body with a corresponding strengthening of its roof. In all such intrusions there will also be the continued presence of country-rock buttresses still remaining unassimilated.

Whether a stoped-out block sinks in the magma but thousands of feet or miles from its former position in roof or wall, that block must undergo an increase of pressure, and, with the greatest probability, an increase of temperature.[a]

The added pressure would have, according to the experiments and field studies of Barus, Doelter, Daubrée, Fouqué, Michel Lévy, and others, the secondary effect of increasing in the magma the capacity of retaining water and other solvents, even at very high temperatures.[b] So important are other experiments in this connection that a brief résumé of certain results accruing from them must be given.

The solubility of rock-forming minerals in silicate magmas has been shown by fusion experiments to depend on (*a*) the temperature of the magma; (*b*) the chemical composition and fluidity of the magma; (*c*) the fusibility of the minerals, and (*d*) on pressure. Doelter has been able to prove that, under one atmosphere of pressure, all the common types of rock-forming minerals are completely soluble in certain representative magmas at temperatures only slightly above those of the respective consolidation points of the latter. These magmas were made from granite, obsidian, common basalt, limburgite, phonolite, foyaite, leucite-basalt, leucitite, hornblende-andesite, and nepheline-basalt—a magmatic range so wide as to demonstrate the practical certainty that all silicate magmas have similar solvent properties. He further shows that the melting point of a silicate rock occurs at about the average temperature of fusibility of its constituent minerals. Long before, Bischof easily dissolved clay-slate in fluid lava, using a bellows furnace for fusion.[c] These important deductions

[a] Perhaps the block would sink to the zone of pressure-solid magma.

[b] Among the more recent papers, cf. C. Barus, Am. Jour. Sci., Vol. XXXVIII, 1889, p. 408, and Vol. XLI, 1891, p. 110; C. Doelter, Centralbl. f. Min., etc., 1902, p. 550, and Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 218.

[c] Chem. u. Phys. Geol., Supplement, 1871, p. 98.

from laboratory investigations correspond to the facts of outdoor nature. Well-known practical examples may be found in the fused and greatly corroded granite inclusions in the basalts of the Auvergne, and again in the complete disappearance by fusion of the "floating islands" in the caldera of Kilauea.[a] The high fluidity of the normal plutonic magma would likewise facilitate the complete solution of foreign fragments, as experimentally proved by Doelter.

It is true that the direct influence of pressure is directed toward elevating the melting points of silicate mixtures, though probably not in a degree proportional to the amount of the pressure.[b] Yet that effect on the solvent power of the magma may be much more than counterbalanced by the indirect effect of pressure in retaining water and other solvents. Once molten, pressure tends to keep silicate magmas molten, since it lowers the temperature point of consolidation.[c] In determining the solvent power of a plutonic magma, temperature furnishes here, as in fixing the melting point, the "coarse adjustment," as pressure furnishes of itself the "fine adjustment."

In conclusion, then, it seems legitimate to regard the conditions of the abyssal portions of plutonic magmas as conspiring toward the perfect digestion of a submerged foreign rock fragment during all the time of intrusion except during the short period preceding final consolidation. Even so uncompromising an opponent of the theory of contact digestion by stock magmas as Brögger admits that such assimilation can be, in the greater depths, exceedingly important, "ausserordentlich bedeutend."[d]

Since it is probable that magmas are more or less completely saturated solutions,[e] there would doubtless be a volumetric increase on the fusion of each block at whatever depth it attained, an increase comparable to that demonstrated in fusion experiments at 1 atmosphere of pressure. The question at once arises as to what compensation can be made for the increased bulk of rock matter below the earth's surface incident to abyssal assimilation on a large scale. Two possibilities suggest themselves in the face of the hydrostatic problem involved. Either volcanic outflow elsewhere or secular upheaval in the region would satisfy the conditions. The latter would seem to be more likely of fulfillment in regard to stocks and batholithic intrusions generally. It is to be noted that magmatic stoping would tend to weaken the earth's crust immediately above the intruding body, and there secular elevation of the surface would be particularly looked for. There may, in this way, be found one cause of the huge buckles filled with the "central granites" of Alpine mountain chains. This implies

[a] J. D. Dana, Characteristics of Volcanoes, New York, 1891, p. 176.

[b] Doelter, Tscher. Min. u. Petrog. Mitth., Vol. XXI, 1902, p. 221.

[c] Oetling, op. cit., p. 370.

[d] Die Eruptivgesteine des Kristianiagebietes, Vol. III, 1898, p. 350.

[e] Lagorio, Tscher. Min. u. Petrog. Mitth., Vol. VIII, 1887, p. 504. Cf. Delesse, Bull. Soc. Geol. France, ser. ii, Vol. IV, 1847, p. 1383.

that the doming of the great intrusive masses of the Christiania region, attributed by Brögger to laccolithic injection, may, in reality, be due to this crustal weakening and buckling by magmas working up from the "ewige Teufe," but at present it must remain only the suggestion of a possibility, as the writer has no personal knowledge of the region.

It is, moreover, worthy of inquiry whether this sort of live energy of intruding granitic magma may be responsible for many of the well-known cases where the secondary structure planes in the invaded formations wrap around their respective intrusive bodies. Examples are seen in the highly developed peripheral cleavage and schistosity parallel to the outlines of such magmas in the Rainy Lake region[a] and in the Black Hills.[b] Such structures could certainly be produced by the force of magmatic expansion, provided that force be sufficient in amount, for it must be exerted always normal to the chamber walls.

If the foregoing reasoning is correct, the preparation of the chambers within which the stock bodies of Ascutney Mountain now rest was carried out by mechanical, piecemeal disruption of each invaded terrane by the attack of the magma on the main contacts. This physical action was accompanied by chemical assimilation at greater depths. Consequently, at those depths the magma must become more and more mixed as the result of assimilation. Each successive eruption from the magma basin beneath may be expected to show indications of the gradual alteration of the magma by the incorporation of foreign substance. This important corollary has to do with the great question of the origin of the igneous rocks, a subject which, in spite of all its complex difficulties, must here be dwelt upon so far as to show agreement or disagreement with the hypothesis just outlined. But a less important, although significant, test of the hypothesis may first be noted.

The hypothesis of rifting not only gives adequate reason for the very general sharpness of contact between an irruptive and its country rock, but also goes far to explain the observed lack of enrichment of the endomorphic zone with the material of the country rock. The blocks would be likely to suffer most from solution in the magma after they had begun their rapid downward journey. They would yield up their substance along the whole path. There would thus be a tendency toward an equal distribution of the absorbed material throughout the magma. In any case, there would be far less impregnation of the endomorphic zone with the substance of the invaded formation than that demanded by the supposition of the slow digestion of the latter in place. In so fluid a magma convection currents would tend still further to destroy any contrast of composition between the endomorphic zone and the body of the intrusive.

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[a] Lawson, Ann. Rept. Geol. and Nat. Hist. Survey Canada, 1887, Part F, map.

[b] Van Hise, Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, pp. 687 and 815.

EVIDENCES OF DIFFERENTIATION.

In turning to the main problem still awaiting us, the relation of the hypothesis of rifting, overhead stoping, and abyssal assimilation to the sequence of the eruptive rocks at Ascutney Mountain, it must be be stated in advance that differentiation in the usual sense of that term has, it is believed, been operative in the production of these rocks. This illuminating principle seems to win added credibility every year, as the petrological facts concerning consanguinity, complementary dikes, etc., become more numerous and more clearly ascertained. Without entering further into the general question, the course of our argument demands that some of the concrete evidences for the value of the principle be noted as the result of a study of Ascutney Mountain.

Direct witness to the fact of differentiation is found in the abundant and remarkable basic segregations from most of the stocks and dikes. Moreover, the "blood relationship" in mineralogical and chemical composition of the main rock bodies of Little Ascutney, Pierson Peak, and Ascutney Mountain proper, occurring as they do in so strikingly different geological associations, and the close agreement in composition with the distant syenitic rocks of Essex County, Mass., Killington Peak, the Adirondacks, Rigaud Mountain, Quebec, and the eastern townships of Quebec, seem to indicate that strict chemical and physical laws, and not fortuitous similarity in the products of assimilation, govern the particular groupings of metals and oxides found in the respective intrusives. The occurrence of nordmarkites in all of these regions must be regarded as the result of the independent assertion in each region of one and the same set of laws of attraction and concentration in an originally more complex rock magma rather than the result of multiplied consolidations of one great nordmarkitic magma underlying all this part of North America.

Further, the conclusion that mere assimilation of the invaded sedimentary terranes by a magma can not be used to explain the intrusives of this part of the world is rendered all the more probable by a detailed comparison of the Ascutney eruptives with those of Mount Shefford, as described by Dresser.[a] The Canadian intrusives named in the order of injection are essexite, nordmarkite, pulaskite, camptonite, and bostonite. The first of these is considerably more alkaline than the Ascutney diorite analyzed, but is probably close chemically to phase *e* of the Basic stock. Macroscopically, the Ascutney diorite and the Shefford essexite are remarkably alike in general habit, and the writer has seen a coarser phase of the latter which has the poikilitic bisilicates and other detailed features of the Ascutney gabbros. As striking similarity characterizes the green nordmarkites of the two mountains. These facts seem to prove conclusively that definite chemical and physical laws have governed the formation of

[a] Am. Geol., 1901, Vol. XXVIII, p. 203.

each special magma which crystallized after irruption into the rock bodies now exposed to view. There has been some post-eruptive differentiation in the Shefford intrusions, as they possess basified endomorphic zones. Dresser holds that the essexite, nordmarkite, and pulaskite form the filling of a laccolithic space in the Lower Silurian sediments of Shefford Mountain. Accepting his view of the mode of intrusion, preeruptive differentiation from a magma originally composed of a mixture of these special magmas, might be credited with a full explanation of the Shefford rocks, though even then the possibility is quite open that the original complex magma had been formed by the considerable digestion and assimilation by a still earlier magma, of the Trenton slates and other sediments through which the eruptions took place. On the other hand, the fact of some kind of assimilation preparatory to differentiation at Ascutney can hardly admit of doubt.

The differentiation of the alkaline rocks in the area, on the hypothesis outlined for Ascutney, would be local and confined to a magma which had been more or less strongly affected by the "mise en place" of the Basic stock. If we have anywhere an igneous formation approximately representing the main magma which underlay the region before the intrusion began, it must be found in that stock. All subsequent intrusions might, on account of the intermixture of assimilated schists, be expected to show a divergence from the original magma that would be the stronger the later the corresponding intrusive appeared in a series of eruptions. In other words, the windsorite dikes, the nordmarkites, pulaskite, monzonite, paisanite, granites, and aplites are, by the hypothesis, regarded as the product of the deep-seated assimilation of the schists followed or accompanied by the differentiation of these related magmatic types from the mixture due to subcrustal digestion. The high silica, potash, and alumina of the micaceous and quartzose phyllites and gneisses would explain the increasing acidity, the alkalinity, and feldspathic character of these differentiated products, though other features must be credited to differentiation alone.

Just how differentiation takes place is still to be reckoned among the mysteries of geology. There is no doubt that several determinative factors must be taken into account. Without in any way wishing to question the validity of the other causes, the writer will here briefly instance one of them as seeming to be of more general application. Rosenbusch has published the view that the separation of differentiated products may be due in part to the gravitative effect, whereby the more acid and lighter constituents of a complex magma become segregated and float upon the more basic and heavier residue.[a] It is supported by the valuable observations of Morozewicz in synthetic experiments and in the study of glass furnaces.[b] Doelter

[a] Mikroskopische Physiographie d. Min. u. Gest., Vol. II, 1896, p. 552.
[b] Tscher. Min. u. Petrog. Mitth., Vol. XVIII, 1898, pp. 170 and 238.

has pointed out that such results adhere to exceptional cases, both in his own experiments and in those of the Russian investigator; yet their significance is still great, since they agree with Gouy and Chaperon's theoretically deduced principle of gravitative stratification in saline solutions,[a] as well as with some positive field observations. For example, Sir A. Geikie describes the separation of a lower layer of picrite and an overlying layer of olivine-basalt in the same lava flow, and finds it probable that similar differentiation has taken place in basic sills.[b] It is at least worth while to apply the gravitative theory to the Ascutney magmas, so far as to state briefly the course of events entailed.

By the separation of the differentiated products, the uppermost layer would, by the antecedent addition of the abundant silica from the digested schists, become more and more acid as the assimilation progressed. The aplites and granite would appear as the latest products (excepting the complementary dikes) of a differentiation dependent on the assimilation for its final expression.

Opposed to the hypothesis is the more usual view of simple differentiation as explanatory of the eruptive sequence. The latter has been well expressed by Brögger for the similar sequence in the Christiania region. He points out the general harmony existing between the theoretical order of differentiation, the order of eruption in the province, and the order of crystallization in the various rocks.[c] On the same principle the oldest Ascutney stock would be regarded as of the nature of a gigantic basic segregation which had absorbed into itself the basic orthosilicates and metasilicates of lime, magnesia, and iron before the crystallization, from the same original magma, of the syenites and granite where the dark-colored constituents are so poorly represented.[d] The possibility of mere differentiation (without assimilation) producing the Christiania rock bodies is due, according to Brögger, to the peculiar laccolithic nature of the intrusions in that province. The preparation of free space for the play of chemical reactions leading to differentiation is quite in contrast with that hypothecated for the Ascutney area, though many of the rock types of the two regions are extremely similar. Brögger has pronounced against the assimilation theory of Kjerulf and Michel Lévy, largely for the reason that it fails to meet the controlling test, the proof of chemical sympathy between the formation invaded and the igneous body supposed to have performed the digestion. Thus the granite of the Christiania region contains scarcely 0.5 per cent of CaO, although the Cambrian and Silurian beds through which the intrusions occurred contain as large an average as 24.5 per cent of the same oxide.[e] The objection does not, however, apply to the modified assimilation

[a] Ann. de Chimie et de physique, 6th ser., Vol. XII, 1887, p. 384.
[b] Ancient Volcanoes of Great Britain. London, 1897, Vol. I, pp. 419 and 442, and Vol. II, p. 310.
[c] Die Eruptivgesteine des Kristianiagebietes, Vol. II, 1895, p. 175.
[d] Cf. Zeit. für Kryst., Vol. XVI, 1890, p. 86.
[e] *Die Eruptivgesteine des Kristianiagebietes*, Vol. II, 1895, p. 129.

hypothesis as outlined in this chapter. Brögger's own cross sections would imply that the Cambrian and Silurian limestones were deposited on Archean crystalline schists. The vertical thickness of this formation is probably several times as great as the thickness of all the Lower Paleozoic limestones combined. Differentiation working on the magma produced by the mixture of the digested material of both limestones and schists might very well give a granite with a low content of lime. Be the method of intrusion what it will, the similarity of the Norwegian and Vermont rocks seems to point unmistakably to the truth of the main principle of differentiation—the tendency toward definite chemical and mineralogical segregation in a silicate magma, irrespective of how that magma was prepared.

As the specific gravity of the acid magmas must in every case be lower than that of the original basic magma, the latter would tend to rid itself continually of the foreign substance being dissolved from the sunken blocks. We have seen that the latter would sink deeply. Whether this gravitative cleansing be perfect or not at a moderate depth of, perhaps, a mile or two below the original magma surface, the magma might there still be quite basic. If we now imagine a prolonged period during which the overlying acid-alkaline intrusives were completely crystallized and, afterwards, a limited fracturing of the whole compound terrane, we can secure some explanation of the final series of basic dikes. They would represent the product of renewed eruptive activity from the deep-lying, still molten magma pressed upward along the easy paths of the fractures. The common occurrence of the diabase dikes and lavas through the whole length of the Connecticut Valley and in many parts of the Appalachian system suggests correlation with this hypothetical explanation. Possibly the camptonites are nothing more than dikes of diabase which have absorbed a small amount of ferrous iron and alkalies from the syenites through which they have found their way. Nevertheless, in spite of the difficulty of determining the place and exact manner of the differentiation of complementary dikes in general, the possibility that these youngest dikes correspond to the basic poles of secondary differentiation can not be excluded. Nor is it necessary to the hypothesis of abyssal assimilation that either alternative be established, for the hypothesis must be linked with the belief in secondary differentiation.

THE PETROGENIC CYCLE.

Finally, it should be observed that the whole series of events leading from the beginning of the invasion of the oldest stock to the irruption of the youngest stock and dikes might, after the solidification of the last of these, be followed by a resumption of plutonic activity. There might thus be repeated the sequence of changes memorialized in the existing rock bodies—basic to acid through intermediate types. Or any part of the cycle might be repeated, whereby

relatively basic irruptions into the schists would be followed by more acid ones. Or, thirdly, the cycle represented in the unsqueezed igneous rocks of the present mountain might have been preceded by an older cycle, the records of which are still buried deep within the schistose formations in the neighborhood. Such an earlier cycle would account for the amphibolites and aplitic sheets which antedate the last great period of folding and dynamometamorphism in the schists.

SUMMARY AND GENERAL APPLICATION.

In order to bring this hypothesis of overhead stoping, abyssal assimilation, and differentiation into relation with the general problem of the plutonic rocks, it will be expedient to recapitulate (I) the essential facts of observation in the Ascutney area, (II) the results of experimental investigation on the specific gravity of the Ascutney rocks and on silicate magmas, and (III) the conclusions won from the correlation of both groups of considerations.

(I) The Ascutney irruptive bodies exhibit the following characteristics:

A series of true stocks ranging from the oldest, most basic, and least alkaline to the highly alkaline, youngest, and most acid, followed and accompanied by groups of aplitic and lamprophyric dikes.

Two of the stocks (Basic stock and Main stock) characterized by a noteworthy heterogeneity; the other three by just as striking homogeneity.

An almost entire lack of sympathy between the structural planes in the country rocks and the form of each intrusive body.

Conclusive evidence that the different magmatic chambers were not prepared by circumferential faulting.

In each stock a decided lack of any enrichment of the endomorphic zone by substance dissolved from the invaded formations; a general freedom from foreign inclusions in the interior, with a characteristic abundance of angular inclosures near the contacts; an exceedingly sharp line of contact with the country rocks; equally sharp contacts of the foreign fragments and their respective hosts; lack of direct sympathy between the composition of the intrusive stocks and of their respective country rocks.

The existence of many long and narrow, apophysal offshoots from each stock, betokening their high fluidity at the time of intrusion.

The presence of many basic segregations in four out the five stocks.

The mineralogical and chemical characters of the stock rocks which, compared among themselves and with the rocks of other petrographical provinces, compel belief in some kind of differentiation of the Ascutney igneous bodies from a common magma.

(II) The experiments of Barus, Delesse, Daubrée, Doelter, Oetling, Morozewicz and others have shown—

That representative natural or artificial silicate mixtures at ordinary

atmospheric pressure become thinly molten at a temperature only slightly above that of solidification.

That, in every instance, a great increase of volume characterizes the change from the solid to the molten state.

That the corresponding difference of density is, no doubt, essentially preserved under plutonic conditions.

That the chief rock-forming minerals are soluble in all of the melted silicate mixtures yet investigated and at the temperatures ruling when those mixtures are thinly molten.

That pressure aids the solubility indirectly by retaining water and other mineralizers in the magma, but retards it, probably in much less degree, by raising the temperature of fusion for silicate minerals.

That there is evidence of differentiation in molten silicate magmas by gravitative effect.

Numerous specific gravity determinations on the solid Ascutney rocks show that the lightest of these would, under the same conditions of pressure as the densest of the magmas (that of the Basic stock), sink on immersion in that magma.

(III) The conclusions necessitated, it is believed, by these facts are:

1. That the various chambers now occupied by the igneous bodies were not opened by bodily movements in the earth's crust, but by some kind of assimilation of the invaded formations.

2. That this assimilation did not take place, except in subordinate degree, by caustic solution on the main contacts.

3. That, even in its relatively inactive state near the moment of final consolidation, each magma was capable of rifting off numerous large and small blocks from the walls with which it came in contact—blocks now visible because the magma was then so toughly viscous as to support them in suspension.

4. That during the much longer period of high fluidity each magma was capable of still more powerful rifting action.

5. That throughout that period there must have prevailed a more or less steady rain of the rifted blocks downward into the lower depths of the magma and a corresponding enlargement of the magma chamber, the size of which would depend on the time during which the action continued; independent testimony may be had of the high probability that the time taken in all plutonic intrusion is very great.

6. That in the abyssal region the blocks must undergo active solution by the magma, which would thus become mixed and gradually more complex.

7. That some compensation for the increased volume of the rock digested must be made—suggesting either surface extrusion from another part of the same magma basin or secular upheaval of the earth's crust above the basin.

8. That the original magma was at least as basic as the gabbroitic phase of the oldest stock.

9. That there would be a tendency for the mixed magma to become more and more acid by reason of the assimilation of the schistose terranes.

10. That this magma would be expected to differentiate by slow gravitative action, through which the lighter, more acid submagmas would float on the heavier basic residues.

11. That such differentiation must be supplemented by other causes, real and universal, though at present ill understood, leading to a comparatively definite splitting of the main magma; thus homogeneous rock bodies would be produced similar to those in other parts of eastern North America and elsewhere.

12. That the Ascutney stocks are the crystallized product of such differentiation from an ever-changing magma constantly enriched by assimilation.

13. That the series of petrogenic events at Ascutney constitute a cycle that might be repeated either as a whole or in part within the same area.

14. That the later basic dikes may be explained as the beginning of a second petrogenic cycle, or as the basic poles of a secondary differentiation.

Now, the facts of field observation at Ascutney Mountain, with two possible exceptions, correspond to possible characteristics of most of the granitic intrusions of the world. The heterogeneity of the Basic stock and of the Main stock is doubtless of a higher order, and the basic segregations in the latter are more numerous than in the normal granitic mass. Yet these contrasts may be largely explained by the action of secondary differentiation. The experimental results of investigation on melted silicate mixtures are manifestly capable of general application. There is, accordingly, reason to believe that the hypothesis summarized in the list of conclusions concerning the Ascutney eruptives may be applied to most stocks and batholiths.

THE UNIVERSAL EARTH MAGMA.

If this hypothesis be accepted for stocks and batholiths generally, and if dikes, sheets, and laccolithic intrusions (including all such as have been conditioned by the action of hydrostatic pressure on a magma entering spaces opened by bodily crustal movements) are the results of the eruption of submagmas differentiated from the deeper-lying and greater magma produced by the incorporation of invaded formations, the further inquiry as to the original composition of such assimilating magma thus becomes a matter of special interest. The required space can not here be taken for a full discussion of this question, even if only the limited number of facts now known concerning the subject were given full statement. Special diffidence may be felt in approaching this most difficult theme. Yet certain preliminary considerations are offered, primarily those which, in the opinion of the writer, do not at the present time receive the full share

of attention that they should have in the problem of the earth's interior; taken together, they seem to form, in a measure, a test of the foregoing hypothesis.

The evidence is accumulating that the normal order for the eruption of plutonic rocks is that of from most basic to most acid. That the same order may be preserved, on the large scale, in extrusions of lava at volcanic cones is illustrated by Sir Archibald Geikie in his treatise on The Ancient Volcanoes of Great Britain.[a] It seems established, moreover, that the oldest eruptive in the majority of petrographical provinces approximates a gabbro or basalt in composition. Yet the oldest intrusive, by the foregoing hypothesis, is that one which should most nearly represent the original magma, modified as the latter tends to become by the assimilation of the more siliceous crystalline schists and sedimentary terranes.

Again, in those conduits where escape of igneous rock from the earth's interior to the surface takes place to such an extent as to build large volcanoes, we should expect the sequence of eruption to be completed by an effusion of lava more nearly representing the original magma than the antecedent flows. This for the reasons, first, that assimilation (deep-seated digestion of the overlying crust) in the immediate vicinity of the vent would, in that late stage in the development of the volcano, have progressed so far as to have enlarged the conduit to a size suitable to the large cone; secondly, that the vent would by the long continuance of the volcanic activity have become freed from the products of such digestion, and, thirdly, that the latest flows would be derived from the original magma practically unaffected by assimilation. Now, it is a significant fact that the latest extrusive product of our greatest volcanoes, such as Etna, Fusiyama, Chimborazo, Cotopaxi, etc., is without known exception, either basalt or andesite. The unnumbered lofty volcanoes which spring from the floor of the deep Pacific and Indian oceans are, with but few exceptions, capped with basalt or andesite. Indeed, such basic lava seems to be the only igneous rock exposed in oceanic areas making up at least one half of the whole surface of the globe.

Not less important is the equally indisputable fact that the great fissure eruptions of the globe give birth to only one kind of lava, again basaltic. The familiar examples in Iceland, Northwestern Europe, India, the Northwestern United States of America, and the Hawaiian Archipelago, tell no uncertain story concerning the nature of the vast reservoir from which they have derived their enormous volumes of lava. The more acid flows which occur in any one of these regions are insignificant in bulk when compared to the total basic output. The former could be explained, in accordance with the present hypothesis, as the product of differentiation acting on the universal magma influenced by the assimilation of the continental rocks, which are characteristically more acid than that magma. Further,

[a] Vol. II, 1897, p. 477.

we should expect assimilation to be less active in determining the composition of fissure eruptives than in preparing the secondary magmas erupted in volcanic cones or injected in the intrusive form. From the nature of the geological dynamics rendering possible the rapid expulsion of the voluminous flows at great fissures, it is clear that the corresponding magma had, in each case, relatively easy access to the earth's surface, and had not to work its way through the crust. The plateau lavas accordingly merit particular notice in the search for the general earth magma. Too little attention has been paid to the volume, relative abundance, and geological occurrence of the different eruptive types in the extant discussions of the origin of igneous rocks. Those questions must always be of prime importance in deciding on the question of assimilation.

For different reasons, excepting that derived from the enormously greater abundance of basaltic lavas on the earth, Dutton came to this same conclusion as to the nature of the "primordial matter." He has rightly emphasized the importance of the fact that basalt is a "synthetic or comprehensive type of rock." His theory of the derivation of other igneous rocks by simple fusion of sedimentary formations, derived in their turn by atmospheric agencies from this "primordial matter," takes insufficient account of the facts of differentiation learned since 1880. Yet his theory has a suggestive relation to the one proposed in these pages.[a]

Thus, partly by the induction of known facts, partly by the deduction of certain conclusions which are explanatory of a considerable number of related phenomena, we have been led to the view that there is, all round the earth and not far from its present surface, a single fundamental magma of a composition allied to basalt. This magma must probably be regarded as molten only potentially and to uncertain depth by the local relief of pressure. It has been implied that all other rocks may have been indirectly derived from such a magma, though the possibility is not excluded that part of the normal continental intrusive (acid-alkaline) rocks may form the more or less pure equivalent of primal matter differentiated at the surface of the original crust of the earth. It is, of course, evident that we are now face to face with other principal earth problems, most of which are nothing more nor less than true riddles. The nature of the earth's original crust, the antiquity of the ocean basins, the duration and geological history of the Archean era during which most of the siliceous material of the crust was prepared in nearly its present form, the origin of the crystalline schists, the preponderance of potash among the alkalies of continental formations, the explanation of the high soda content of sea water, are among those problems bearing on the hypothesis. It can only be said that the writer has not yet met with insurmountable objections to the hypothesis in the partial solutions now attained for them.

[a] Cf. C. E. Dutton, The High Plateaus of Utah: U. S. Geol. and Geog. Surv. Rocky Mountain Region, Washington, 1880, p. 125 et seq.

The probability that the combined variety and type constancy of the continental igneous rocks are due to both abyssal assimilation and magmatic differentiation is taught not only by a detailed study of a small area like Ascutney Mountain, but as well by a review of the earth's igneous output as a whole. Perhaps the hypothesis founded on this conviction may do something toward removing the difficulty that is felt by most students of igneous rocks; it is the dilemma once well described to the writer by a leading petrologist: "As a geologist, one must believe in assimilation; as a petrographer, he must declare against it."

APPENDIX.

TABLES, LIST OF SPECIMENS, ETC.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives.*

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Camptonite	Basic labradorite (Ab_2 An_3).	Hornblende Augite.	Titaniferous magnetite. Pyrite. Apatite. Decomposition products: Chlorite, epidote, calcite, secondary quartz, kaolin.	Panidiomorphic porphyritic.
Augite-gabbro	do	Augite.	Biotite. Hornblende. Pyrite. Ilmenite. Titanite. Apatite.	Hypidiomorphic granular.
Diabase	do	do	Titaniferous magnetite. Pyrite. Apatite. Decomposition products: Chlorite, epidote, calcite, secondary quartz, kaolin.	Ophitic.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives*—Continued.

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Hornblende-biotite-augite gabbro.	Basic labradorite (Ab_2 An_3).	Hornblende. Biotite. Augite.	Ilmenite. Pyrite. Titanite. Apatite.	Hypidiomorphic granular.
Biotite-hornblende-diorite.	Av. basic oligoclase (Ab_3 An_1).	Biotite. Hornblende.	Quartz. Ilmenite. Pyrite. Apatite. Titanite. Zircon.	Do.
Biotite-augite-hornblende-diorite.	.....do	Biotite. Augite. Hornblende.	Quartz. Ilmenite. Pyrite. Apatite. Titanite. Zircon.	Do.
Essexite	Andesine (Ab_5 An_3). Microperthite. Orthoclase.	Hornblende. Biotite.	Quartz. Augite. Ilmenite. Apatite. Titanite. Zircon.	Do.
Monzonite	Microperthite. Orthoclase. Labradorite (Ab_1 An_1).	Hornblende. Augite. Biotite.	Quartz. Titaniferous magnetite. Apatite. Pyrite. Zircon.	Do.
Windsorite	Microperthite. Orthoclase. Basic oligoclase (Ab_3 An_1).	Biotite.	Quartz. Augite, hornblende. Ilmenite. Apatite. Zircon. Titanite?	Do.

TABLE XIII.—*Mineralogical and structural constitution of the Ascutney eruptives*—Continued.

	Essential feldspars.	Other essential constituents.	Accessory.	Structure.
Pulaskite	Microperthite. Orthoclase.	Biotite	Titaniferous magnetite. Quartz. Titanite. Hornblende. Augite. Apatite. Zircon.	Hypidiomorphic granular.
Nordmarkite	Microperthite (cryptoperthite). Orthoclase. Microcline. Acid oligoclase.	Hornblende. Biotite. Augite. Quartz.	Quartz. (Allanite.) Titaniferous magnetite. Apatite. Pyrite. Zircon. Monazite. Garnet.	Hypidiomorphic granular. Porphyritic. Trachytic.
Biotite-granite	Microperthite. Orthoclase. Microcline. Acid oligoclase.	Biotite. Quartz.	Magnetite. Titanite. Apatite. Zircon.	Porphyritic.
Paisanite	Microperthite. Soda-orthoclase.	Quartz. Hornblende.	Titanite. Ilmenite. Pyrite. Zircon. Apatite.	Panallotriomorphic porphyritic.
Muscovite-aplite.	Orthoclase. Albite.	Quartz. Muscovite.	Microperthite.	Panallotriomorphic.

TABLE XIV.—*Chemical analyses.*

[Analyst, W. F. Hillebrand.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
SiO_2	52.12	55.28	64.62	65.43	64.88	56.51	73.69	56.53	73.03	71.90	59.27	56.01	48.22	49.63	90.91	58.35	45.30
Al_2O_3	16.35	17.23	16.46	16.11	16.24	16.59	12.46	16.47	13.43	14.12	15.76	[a]15.19	14.27	14.40	4.18	21.30	30.51
Fe_2O_3	3.68	1.51	1.82	1.15	1.37	1.35	1.21	1.58	.40	1.20	2.07	2.34	2.46	2.85	.22	.30	.24
FeO	6.02	6.23	2.14	2.85	2.70	6.59	1.75	5.40	1.49	.86	3.57	4.89	9.00	8.06	1.27	6.00	8.80
MgO	4.14	2.69	1.10	.40	.89	2.52	.17	2.67	.14	.33	3.04	4.67	6.24	7.25	.37	2.10	3.11
CaO	7.25	5.60	2.39	1.49	1.92	4.96	.36	4.90	.79	1.13	3.69	4.85	8.45	9.28	.22	.85	.90
Na_2O	3.65	5.42	4.57	5.00	5.00	5.15	4.47	5.59	4.91	4.52	5.63	5.66	2.90	2.47	.77	1.60	1.65
K_2O	2.34	2.12	5.21	5.97	5.61	3.05	4.92	3.80	4.54	4.81	3.33	2.16	1.98	.70	.58	5.63	4.84
H_2O above 110° C	.88	.71	.39	.39	.46	.71	.24	.60	.35	.42	.74	.36	1.66	1.47	.74	.86	1.05
H_2O below 110° C	.25	.20	.13	.19	.19	.21	.14	.23	.18	.18	.23	.90	.28	.27	.06	.31	.26
CO_2	.07	.04	.11	Tr.?	None.	.33	Tr.	.05	Tr.?	.21	.30	Undet.	.15	1.36	.18	None.	Tr.?
TiO_2	2.10	1.64	.81	.50	.69	1.20	.28	1.40	.30	.35	1.12	1.13	2.79	1.68	.28	.87	1.48
ZrO_2	.02	Tr.	.03	.11	.13	.04	.14	.08	.06	.04	.04	....	.08	Tr.?	.02	None.	None.
P_2O_5	.89	.73	.21	.13	.13	.41	.04	.27	.06	.11	.42	.53	.64	.25	.05	.18	.12
SO_3	None	None.	None.	None.	None.	None.	None.	None.	None.	None.	None.	....	None.	None.	None.	None.	.04
Cl	.09	.07	.05	.05	.04	.07	.02	.07	.03	.02	.03	Undet.	.10	.07	Tr.	.03	.04
F	.03	.28	Undet.	.08	.08	.24	.05	.19	.06	.06	.42	Undet.	.05	Tr.	Tr.	Undet.	.04
S (FeS_2)	.24	.07	.19	.07	None.	.06	None.	Tr.	.09	Tr.	.07	.09	.86	.22	.11	.19	.36
Fe_7S_8																.58	.96
NiO, CoO	Tr.	(?)	None.	(?)	None.	Tr.?	None.	Tr.	(?)	None.	Tr.	.03	.08	.04	None.	.03	.02
MnO	.17	.24	.12	.23	.14	.24	.15	.20	.15	.05	.37	.40	.20	.17	Ft. tr.	.13	.20
BaO	.04	.06	.03	.03	.06	.03	None.	Tr.	Tr.	.04	Tr.?	Tr.?	.04	Tr.?	Tr.	.05	.03
SrO	Tr.?	Ft. tr.	Tr.	Tr.	Ft. tr.	Tr.	Ft. tr.	Tr.	Tr.	Tr.	Ft. tr.	....	Tr.	Tr.?	None.	Tr.	Tr.
Li_2O	Tr.	Tr.	Tr.	Str. tr.	Tr.	Tr.	Tr.?	Tr.	Tr.	Tr.	Tr.	....	Tr.	Tr.	Str. tr.	Str. tr.	Str. tr.

[a] Including ZrO_2

CuO	(?)	(?)	Tr.	(?)	(?)	(?)	Tr.	(?)	(?)	(?)	(?)	....	Tr.	(?)	(?)	Tr.	(?)
C	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	(?)	....	(?)	(?)	a.10	b.40	c.17
	100.33	100.15	100.38	100.18	100.53	100.26	100.09	99.98	100.03	100.35	100.10	99.21	99.80	100.17	100.06	99.71	100.12
O=F, Cl	.03	.13	.01	.04	.04	.11	.02	.09	.04	.03	.19	....	.04	.02	....	....	.02
	100.30	100.02	100.37	100.14	100.49	100.15	100.07	99.89	99.99	100.32	99.91	....	99.76	100.15	....	....	100.10
Total S	.13	.038	.10	.036	None.	.03	None.	Tr.	.05	Tr.	.037	....	.19	.12	.056	.31	.19
	2.936	2.822	2.666	2.659	2.683	2.849	2.633	2.756	2.628	2.616	2.661	2.720	2.810-2.869	2.922	2.678	2.673	2.835

[a] Another sample gave 0.06 carbon and 0.42 CO_2. [b] Another sample gave 0.03 carbon and no CO_2. [c] Another sample gave 0.08 carbon and 0.04 CO_2.

1. Biotite-augite-hornblende-diorite from the Basic stock; Notch road.
2. Basic segregation from the quartz-orthoclase-microperthite-bearing hornblende-biotite-diorite; Little Ascutney Mountain.
3. "Windsorite" dike cutting the Basic stock; Little Ascutney Mountain.
4. Nordmarkite with granitic structure; Windsor quarry, north side of Ascutney Mountain.
5. Nordmarkite with porphyritic structure; east end of Ascutney Mountain.
6. Basic segregation in No. 5.
7. Paisanite dike cutting No. 4; northwest side of Ascutney Mountain.
8. Basic segregation in No. 7.
9. Paisanite dike cutting nordmarkite-porphyry dike of Little Ascutney.
10. Alkaline biotite-granite; Ascutneyville quarry.
11. Basic segregations in No. 10.
12. Basic segregations in No. 10; containing more hornblende than No. 11.
13. Camptonite; Ascutney Mountain, near summit.
14. Diabase dike; Ascutney Mountain, north slope.
15. Quartzitic phyllite; cliff west of Ascutneyville.
16. Cordierite-biotite-microperthite-hornfels; north slope of Ascutney Mountain, 100 feet (31 meters) from contact with syenite.
17. Cordierite-corundum-pleonaste hornfels from the same cross section of the exomorphic zone as No. 16; 25 feet (8 meters) from the contact.

TABLE XV.—*List of the more important specimens studied.*

No. 1a and 1b. Basic segregation in biotite-granite.
2. Biotite-granite.
5. Metamorphosed limestone of contact-zone, bearing grossularite.
24. Sericitic quartzite.
32. Biotite-hornblende-diorite.
34. Granite; phase *h* of Main syenite stock.
36. Breccia of Little Ascutney.
42. Green nordmarkite; Main syenite stock (phase *f*).
57. Camptonite dike; Little Ascutney.
59. Microperthite-bearing hornblende-biotite-diorite.
59a. Basic segregation in 59.
60. Paisanite; Little Ascutney.
61. Hornblende-biotite-augite-gabbro.
62. Pulaskite; Pierson Peak.
66. Basic segregation in porphyritic phase *g* of Main syenite stock.
74. Augite-camptonite.
76. Nordmarkite-porphyry; Little Ascutney.
77. "Windsorite" dike; Little Ascutney.
100. Metamorphosed limestone of contact zone, bearing epidote, etc.
105. Endomorphic zone of biotite-granite.
106. Miarolitic phase of 105.
111. Monzonite; phase *i* of Main syenite stock.
113. Segregation in biotite-granite.
114. Unaltered siliceous limestone.
115. Porphyritic phase *g* of Main syenite stock.
120. Diabase dike.
122–136, inclusive. Metamorphosed phyllite of contact zone about the Main stock.
139. Paisanite of Main stock.
141. Basic segregation in 139.
145a. Augite-biotite-diorite dike; Little Ascutney.
147. Augite-biotite-hornblende-diorite; Little Ascutney.
175. Altered aplite.
184. Augite-biotite-diorite.
191. Muscovite-aplite.
192. Augite-gabbro.

INDEX.

O

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 209.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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